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HYDROGRAPHICAL INVESTIGATIONS IN FAEROE WATERS

CRUISE OF THE

M/S "MARGRETHE" IN 1913

BY

J. P. JACOBSEN

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I KOMMISSION HOS C. A. REITZEL
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Introduction

During the spring of 1913, a series of investigations were carried out by the Danish Commission for the Investigation of the Sea, the work including hydrographical observations in the Færoe waters. The vessel employed for the purpose was the »Margrethe«, a two-masted schooner with auxiliary motor, which had been chartered by the Commission, partly with a view to ascertaining how far ships of this type might prove suitable for sea investigations. Its equipment was therefore restricted to such apparatus as was purely indispensable, this being especially the case as regards the hydrographical installation.

In conformity with the above conditions, the scheme of work for the Færoe investigations was limited to examination of local fjords, with some observations on the Færoe Bank, which lies south-west of the islands themselves.

The object of the present work is to set forth the results obtained by the hydrographical investigations carried out on this occasion, in which the writer took part. At the same time, a considerable amount of material dating from previous investigations has also been dealt with.

After completion of the investigations at the Færoes, a cruise was made in the Atlantic on board the same vessel. In the course of this voyage, valuable work was done by cand. Jespersen and Capt. Hansen, who succeeded, despite the inadequate equipment at their disposal, in procuring a considerable amount of hydrographical material. Unfortunately, however, a great deal of the water samples collected were lost with the wreck of the »Margrethe« on Anegada Reef in December 1913. A discussion of the results obtained will be given in another paper.

I. Fjord Investigations

1. General view of the hydrographical conditions in the fjords of the Færoes

The fjord investigations referred to in the Introduction were carried out in Trangisvaag and Vaag, Suderø. Previous investigations have also furnished a considerable amount of information from these and other fjords; the greater part of the results obtained have already been published in the Bulletin issued by the International Council[1].

A series of temperature measurements, as well as a considerable number of water samples, were collected in 1910 and 1911 by Capt. Alf Trolle, then Lt. commanding the Inspection vessel »Beskytteren«, who kindly undertook to procure this material. The amount of chlorine in the water samples has since been determined at the Hydrographical Laboratory. I am requested by the Head of this last-named institution, Professor Martin Knudsen, to take this opportunity of thanking Capt. Trolle for the material in question.

[1] Bulletin hydrographique publié par le bureau du conseil permanent international pour l'exploration de la mer, Copenhague.

This material has not previously been made public, nor has any work yet been issued dealing with the Færoe Fjord investigations as a whole. I have therefore included in the tables all such observations of temperature and salinity as have been made up to time of writing. A number of determinations as to amount of oxygen have also been added. The tables in question will be found at the end of this paper.

In considering the present material, it will be natural to commence with two series of measurements taken in Trangisvaag in 1913, on the 29th of May and 6th of June respectively.

Fig. 1 shows the position of those stations in Trangisvaag Fjord where the observations in question were made; Figs. 2 and 3 give the position of the isohalines and isotherms in sections of the fjord on the respective days.

Fig. 1. Map showing situation of the stations in Trangisvaag. Investigations of May—June 1913.

The numbers of the stations are marked above the horizontal line indicating surface of the water. Some of the figures for temperature and salinity have been noted on the sections; others have, however, been omitted owing to want of space. The places at which observations as to temperature were made are indicated in the sections by a dash (—) to the left of the vertical line denoting the station, a similar mark to the right of the station marking the spots where observations of salinity were made.

From the longitudinal sections through the fjord it will be seen that in the outer part (Station 18) the salinity is uniform from surface to bottom, and practically identical on both dates, all observations falling between the limits 35.14 and 35.17 $^0/_{00}$. The same salinity is also found in the lowest water layers in the inner part of the fjord.

At the surface, however, the salinity of the inner portion of the fjord is lower than in the outer waters. It should nevertheless be noted, that not until the innermost station on the section (Stat. 2) is reached does the salinity fall below 34 $^0/_{00}$, while the position of the 35 $^0/_{00}$ isohaline shows that the amount of water within which salinity fails to reach this latter figure is but small.

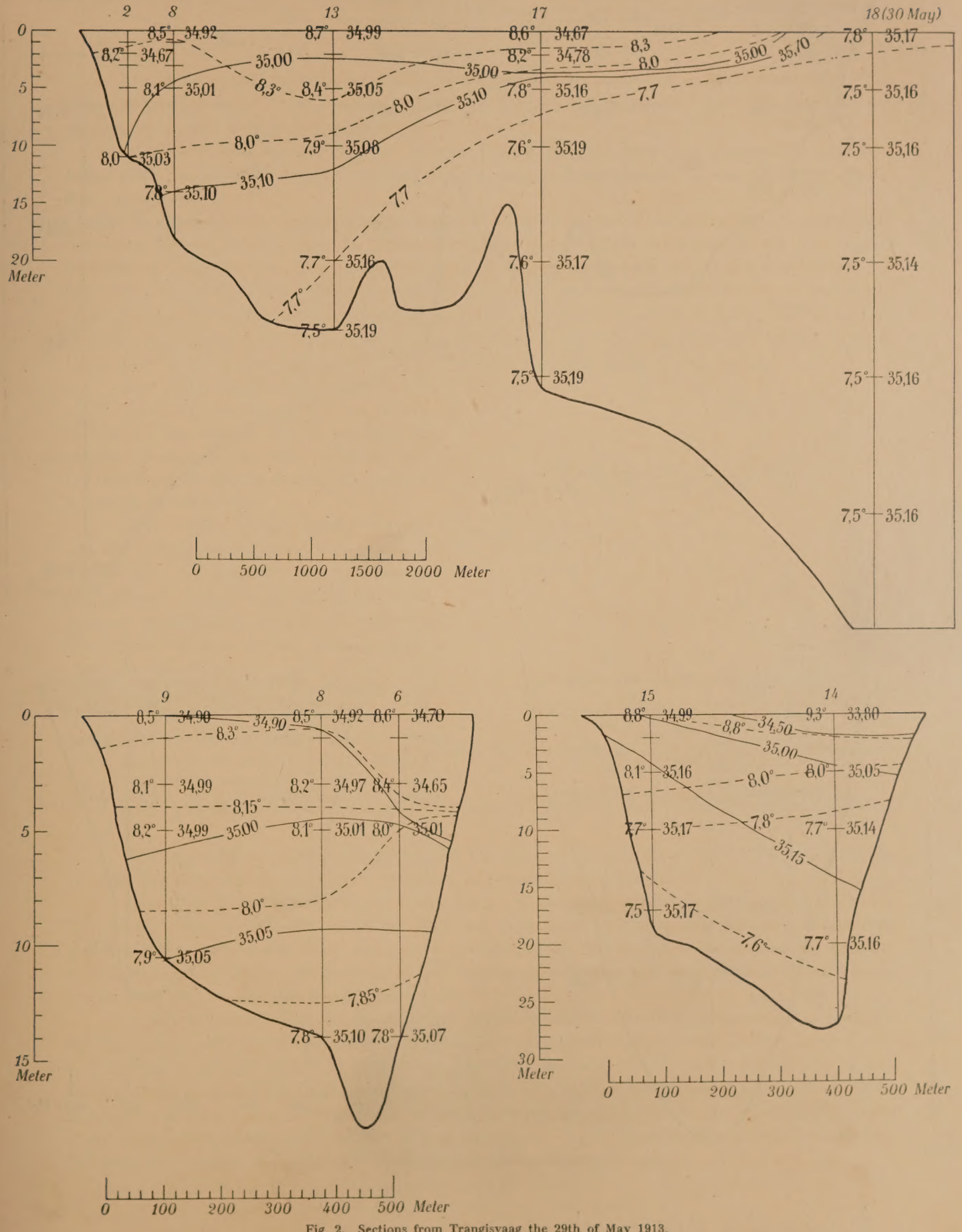
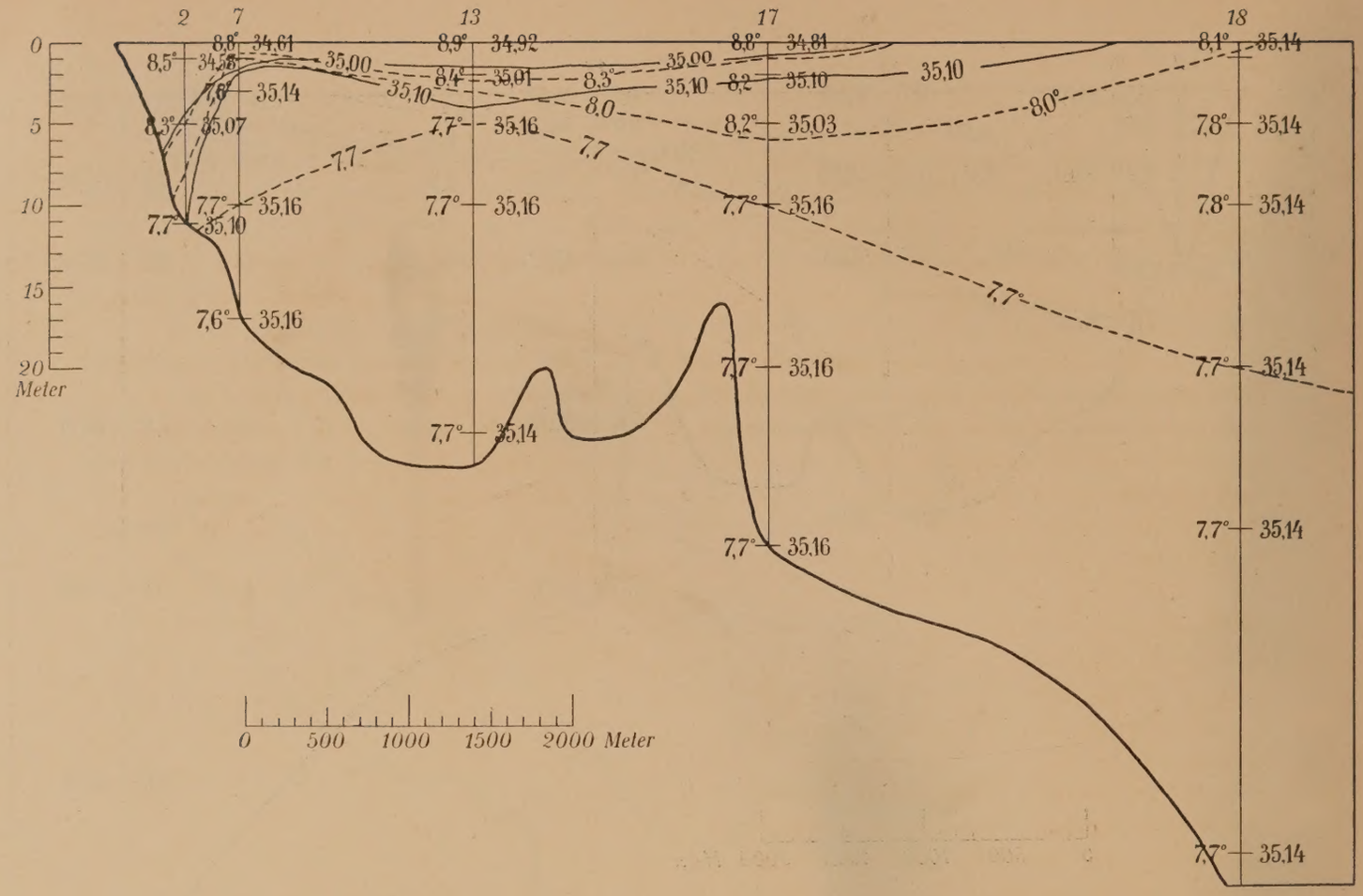
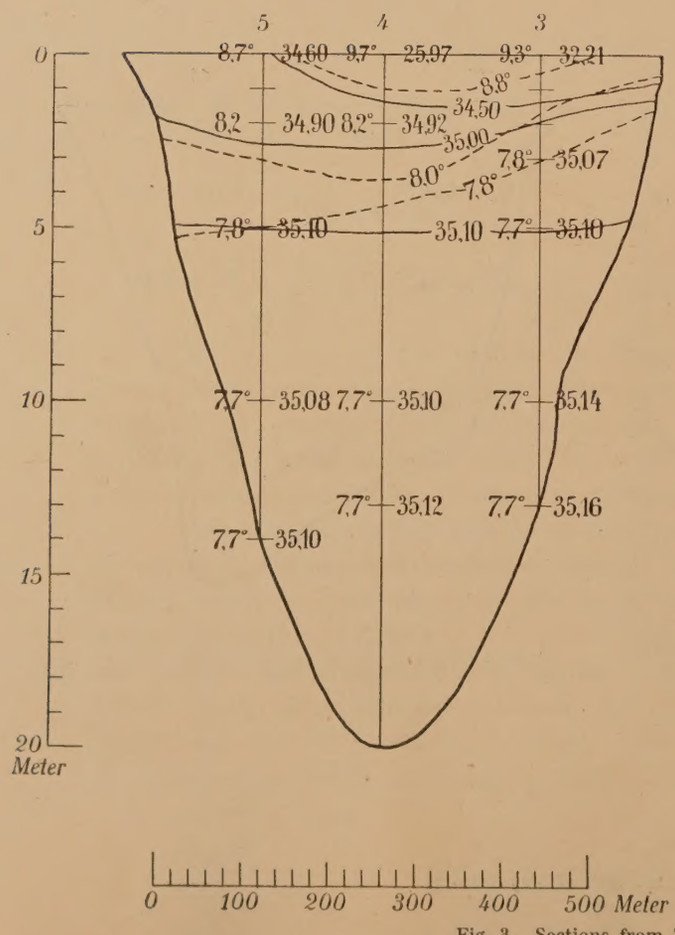


Fig. 2. Sections from Trangisvaag the 29th of May 1913.





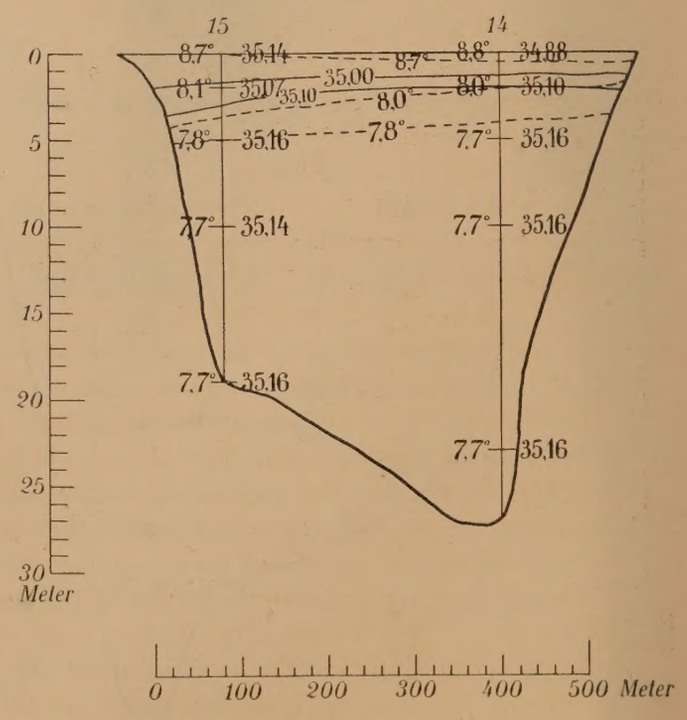


Fig. 3. Sections from Trangisvaag the 6th of June 1913.

It will be noticed that the isohalines exhibit the characteristic oblique course known from other waters, e. g. the Kattegat. This is due to the fact that the influx of fresh water takes place for the most part in the innermost portion of the fjord.

The position of the isohalines in the cross sections does not reveal any characteristic difference between the two sides of the fjord; the comparatively great variation apparent is doubtless due to purely local conditions.

On glancing at the distribution of temperature in the longitudinal section, it will be noticed that the surface layer is on the whole somewhat warmer than the bottom layer, which by the way, was to be expected, since the water is in process of warming. It will further be seen that the temperature of the water with low salinity somewhat exceeds that of the salter water in the bottom layer and in the outermost part of the fjord. Such differences of temperature as are apparent, however, exhibit far less regularity than is the case with the salinity; a fact which is not surprising when we consider that the warming of the fjord takes places much more irregularly than the influx of fresh water.

The deep water temperature in the outermost portion of the fjord is, as already mentioned, the lowest, and its variation in progress of time is very slow; it will be noticed that from 29. May to 6. June, the increase is only from 7.5 to 7.7.

This variation of the bottom temperature was investigated at Station 17 by automatic registration. The apparatus employed for the purpose was constructed by placing one of the ordinary thermographs, as used for registering temperatures in air, in an iron casing, so tightly closed as to preclude any influx of sea water when on the bottom. The thermograph was, however, rendered more sensitive than those generally used, being furnished with an extra bulb, which was connected up to the original one by means of a tube. On testing the apparatus thus constructed, it was found that the indicator moved 4 mm. when the temperature was raised 1°.

Fig. 4. Map showing situation of the stations in Vaag. Investigations of May—June 1912 and 1913.

This apparatus was four times exposed at the place mentioned, for about a week at a time; in no case, however, had the temperature undergone any measurable variation.

The hydrographical conditions in Vaag Fjord are altogether similar to those already noted for Trangisvaag. We have measurements for 1912 and 1913, partly from the same stations, and in both years from the same season, May—June. The position of the stations will be seen from Fig. 4, while in Figs. 5 and 6 are shown the positions of the isotherms and isohalines in sections through the stations, in the same way as indicated for Trangisvaag Fjord.

It will be noticed that only the innermost station exhibits a salinity of less than 34 $^{0}/_{00}$, while the salinity in deep water at the outermost station (No. 6) is exactly the same as that for deep water in the outer portion of Trangisvaag Fjord; this being, moreover, the case in both years. In 1913 the salinity in the outermost part of the fjord is uniform from surface to bottom, which corresponds with the facts noted for that year in Trangisvaag Fjord. In 1912, however, the outermost portion of the fjord exhibits a somewhat lower salinity at the surface than at the bottom. In the inner portion of the fjord, we find the same characteristic obliquity of the isohalines as in Trangisvaag Fjord.

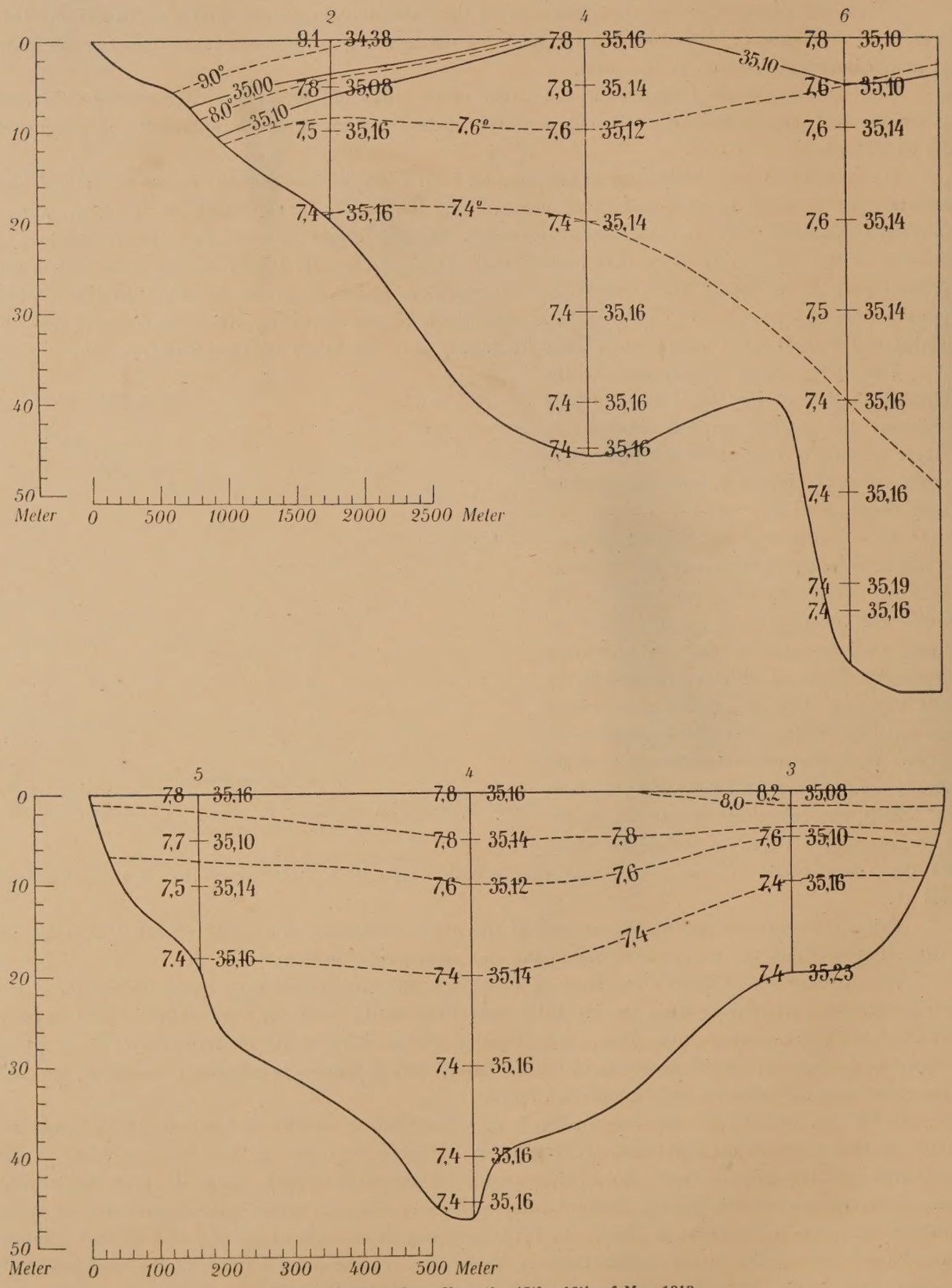


Fig. 5. Sections from Vaag the 15th—16th of May 1912.

We may doubtless be justified in supposing that the hydrographical conditions in Færoe fjords, such as Trangisvaag and Vaag, will in the main features always be as above described. As to how far the salinity in deep water in the outer portions of the fjords may at all times exhibit exactly the same value as here found is less certain, more especially since the investigations here described were all carried out at the same season of the year. On examining the observations from the other fjords, we find that the salinity in deep water varies more than in Trangisvaag and Vaag; on the other hand, it should be borne in mind that the water samples from some of the fjords have been collected as occasion offered, and kept for some considerable time before titration could be made.

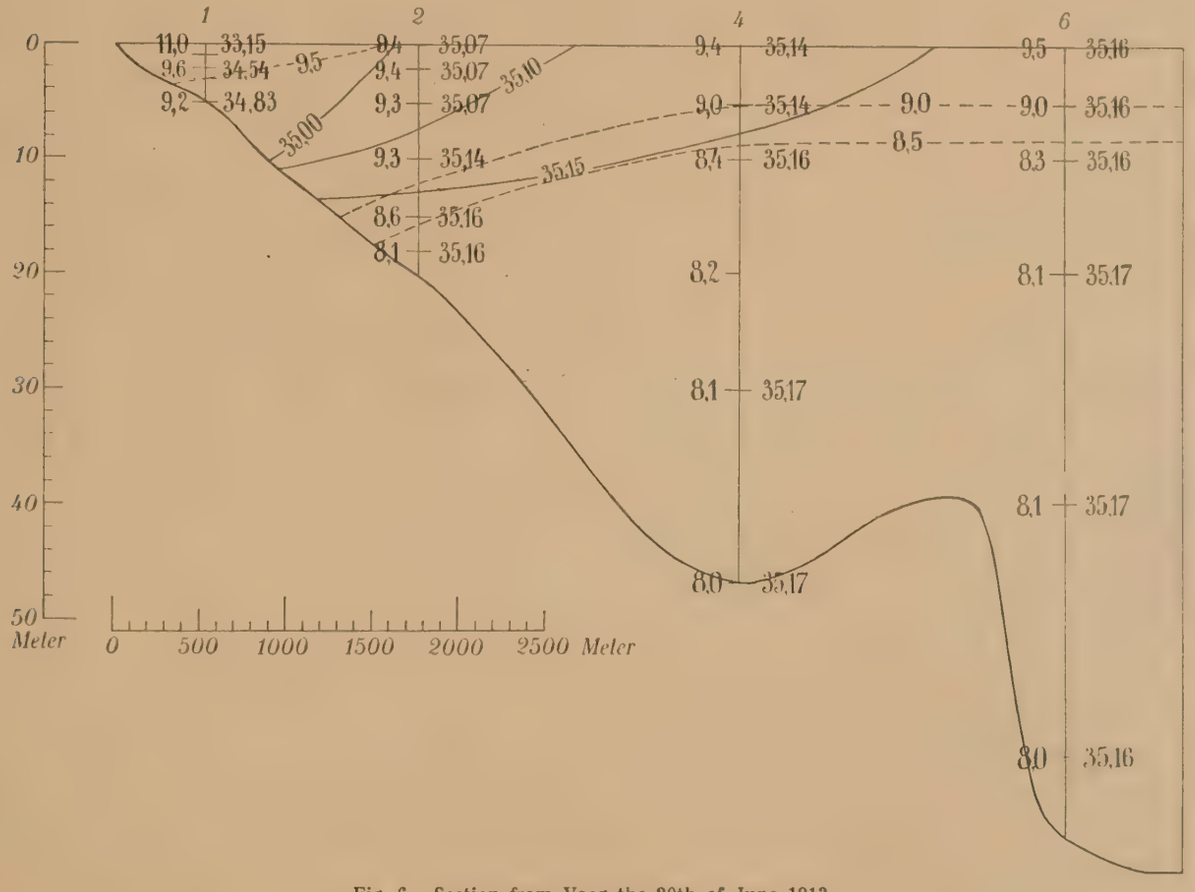


Fig. 6. Section from Vaag the 20th of June 1913.

For Vaag Fjord, we have a determination of salinity from June 1910, at 23 metres depth, of 35.07 ‰, which is considerably lower than the values found in 1912 and 1913.

Any decisive comparison of the salinity of the water in the outermost deep waters of the fjords at different seasons of the year must necessarily be a matter of difficulty, on the basis of the material available; it would seem, however, that the salinity is probably at its lowest during the winter, which is to be expected, owing to the greater rainfall and slighter evaporation at this season of the year.

In the tables on p. 46 will be found some values for amount of oxygen, as determined for different depths in the different fjords in 1910 and 1912; these show that the water has in all cases been more or less supersaturated with oxygen, and as all the figures are for May or June, it is reasonable to suppose that this is due to the developement of oxygen occasioned by plankton organisms.

2. Movement of the water in Trangisvaag Fjord, and causes of same

Having now given, in the foregoing, a brief survey of the hydrographical conditions, we may proceed to consider the question as to how such distribution of temperature and salinity originates. I therefore propose to examine this point more closely, as regards Trangisvaag Fjord, this being the water from which most observations are available.

The hydrographical conditions in this fjord may at the outset be presumed to present a certain similarity to those with which we are acquainted, on a larger scale, in the Danish waters of the Kattegat and the Belt Sea.

The position of the isohalines and isodenses in Trangisvaag Fjord is similar to that noted in the south of the Kattegat; we might therefore expect to find an outward movement of the upper layer and an inward movement of the lower, corresponding to those found at the Schultz' Grund Light-ship [1]). At the same time, there must also be inward and outward movements occasioned by the wind, and finally, it must be presumed that a backward and forward movement takes place as the amount of water in the fjord increases or decreases. Such movement as the last named will occur when any change is effected in the level of the water outside the fjord, which again may be due to wind or tide, or to alteration in the barometric conditions.

Preliminary observations made during fairly calm weather at once showed that the contrary movement of currents in upper and lower layers was very slight, if indeed any such existed.

In order to further elucidate this point, current measurements for surface and bottom were made at Stations 3, 4 and 5 (Fig. 1), by means of floating bodies suitably prepared. The locality of investigation was chosen with regard to the position of the isohalines and isotherms, which appeared to indicate that the contrary movement of upper and lower layers should here be most distinctly marked.

The floats consisted of a body furnished with cylinders composed of two iron rings with canvas between, the height of the cylinders being 1 m, and diameter of the rings also 1 m. The cylinders were fastened by a crowfoot to a line, which again was attached to the float; this last consisting of a 6-litre bottle partly filled with water. A stick bearing a flag was inserted in the neck of the bottle. Two floats were used, the line attached to one being quite short, that of the other 10 m long. The former was used for measuring the surface current, the latter at 10 metres depth, as the effect of the current on the bottle, under the prevailing conditions, might be taken as insignificant. The floats were set out from a boat, accurate shore bearings being taken. After the lapse of for instance half an hour, the boat being brought up again to exactly the same bearings, or having remained there at anchor, it was then possible to see how far the floats had moved from the spot in the intervening time, and to judge the distance more or less correctly in metres.

By such primitive means the figures given in Table 1 were obtained. The decimal for velocity is to be regarded as of but slight importance; it is, however, quite evident from the table, that the currents were only very slight in such calm weather as prevailed on the days when the observations in question were made.

The measurements having been made so far up in the fjord, where the isodenses are steep, we may conclude that the currents occasioned in the fjord by differences in specific gravity are quite small.

The principal influx of fresh water takes place at the base of the fjord; as will be seen, however, from the position of the isohalines and from the figures pp. 39 and 40, this fresh water becomes so strongly mixed with the water of the fjord itself, even within Stations 3, 4 and 5, that the surface salinity for these stations generally does not differ by more than abt 3 $^0/_{00}$ from that for the outermost, deep water of the

[1] Meddel. fra Kom. for Havundersøgelser, Bd. II, Nr. 2, p. 63.

Table 1. Current measurements in Trangisvaag Fjord.

Stat.	Date	Time		Depth in metres	Velocity of current cm/sec	Direction of current towards	Wind
		From	To				
4	June 5	6.35 p. m.	7.55 p. m.	0	3,3	SE	Extremely slight
-	— -	— —	— —	10	0,8	SE	
-	— -	8.25 —	9.10 —	0	7,4	SE	Slight breeze blowing outwards through fjord at first; later perfectly calm
-	— -	— —	— —	10	1,5	SE	
4	June 6	9.10 a. m.	9.40 a. m.	0	2,2	NW	Almost calm, but slight breeze inward through fjord
-	— -	9.45 —	10.15 —	5	< 0,3	—	
-	— -	10.30 —	11.00 —	10	1,1	SW	Almost calm
-	— -	11.05 —	11.35 —	0	1,7	SE	Some few slight gusts
-	— -	11.55 —	1.10 p. m.	0	1,1	SE	Very slight breeze
-	— -	1.30 p. m.	2.10 —	0	< 0,2	—	
-	— -	1.30 —	2.10 —	10	2,1	N	
-	— -	2.20 —	2.50 —	0	2,2	W	Blowing a little from the west, in gusts
-	— -	— —	— —	10	0,6	NE	
-	— -	3.05 —	3.35 —	0	2,2	W	Wind from NW (faint)
-	— -	— —	— —	10	1,1	SE	
5	— -	3.50 —	4.30 —	0	1,2	NW	
3	— -	4.05 —	4.45 —	0	1,7	NW	
4	— -	5.00 —	5.30 —	0	1,7	NW	
-	— -	— —	— —	10	0,6	SE	
4	June 7	1.55 —	2.35 —	0	1,2	SE	During these measurements wind freshened up from 1 to 3 Beaufort (from SE.)
-	— -	— —	— —	10	2,9	NW	
4	June 8	10.35 a. m.	11.15 a. m.	0	2,5	SE	Wind from SE (faint).
-	— -	— —	— —	10	1,2	E	

fjord, while the bottom salinity at the mentioned stations is never more than 0.1 $^0/_{00}$ different from this. It is thus not surprising that the currents occasioned by difference in specific gravity should be but slight.

Presuming that the water at all points of a section through Stations 3, 4 and 5 has the same resulting outward movement occasioned by the influx of fresh water from the river, the velocity in the section may then be calculated, given the quantity of water brought down by the river, and the size of the section.

As to the first of these two factors, I endeavoured to obtain some idea by measuring the velocity of the water in the river at a certain point, and the corresponding cross sectional area. The figures obtained were, for the river at the base of the fjord, on 28 May, 0.3 m^3/sec., and on 2 June, 0.35 m^3/sec. These values are, however to some extent based on personal judgement.

Wishing, therefore, to obtain also by other means an idea as to the order of magnitude for the quantity of water introduced by the river into the fjord, I calculated the rainfall for the area drained by the river from 21 May to 15 June 1913.

A table of the daily rainfall at the two stations Vaag and Sand has been kindly placed at my disposal by the Danish Meteorological Institute. The total rainfall for Vaag from 21 May to 15 June I found to be 100 mm, and for Sand 56 mm. The area drained by the river I have calculated, from a marine chart, to be 1.3×10^7 m^2. From this it will be found, that if the quantity of rain water from the area drained were regularly brought down to the fjord, the inflow would be 0.58 m^3/sec. and 0.32 m^3/sec., when based on the rainfall from the stations at Vaag and Sand respectively. In calculating rainfall, we have naturally to reckon with considerable sources of error, as is evident from the different values obtained at two closely adjacent stations. Moreover, in estimating the quantity of water brought into the fjord per given unit of time, allowance must be made for evaporation and for the retardation of the actual inflow relative to the rainfall. If we consider, however, the low degree of temperature (abt. 8^0),

the general moisture of the weather, and finally the steep slope of the outflow, it must be presumed that the principal source of uncertainty lies in determination of the rainfall, this being dependent on local conditions at the different places.

It is therefore by no means unreasonable to suppose that the amount of water brought down by the river during the months in question is between $^1/_3$ and $^1/_2$ m^3/sec.

In this connection I may mention, that on making similar primitive calculations of the quantity of water in the river at Ørdevig, I found this to be about half that noted for the river at the base of Trangisvaag Fjord, whereas the quantity brought down into the fjord by the streams on the northern side was in all about 0.2 m^3/sec. These measurements were not, however, made on the same day as those for the other two rivers. The amount of water in the streams on the south of the fjord was extremely slight.

On measuring out a section through Stations 3, 4 and 5 (Fig. 1), the area of this was found to be abt. 7×10^3 m^2. If the whole of the water brought down by the river passed through this section, then given an equal velocity of all particles, this would be 0.005 cm/sec.; an entirely insignificant rate of current in comparison with what can ordinarily be measured. The supposition that the velocity of the current should be uniform in all parts of the section is of course not in accordance with the actual facts.

From the observations made at these three stations, it will be seen that the upper water layer, down to a depth of less than 1 metre, often exhibits a considerably lower degree of salinity than that from a depth of 1 m downwards. The few observations further tend to show that the salinity in the middle of the fjord is lower than at the sides.

Presuming that water having a salinity of 33 $^0/_{00}$ be passed through an area of the section above, and water with a salinity of 35 $^0/_{00}$ through that below, and further, that the proportion between the two areas be 1—30, then an outflowing current of 2.7 cm/sec. in the former and an inflowing current of 0.085 cm/sec. in the latter would suffice to maintain a constant degree of salinity within the section, and with these two currents, the amount of water brought down by the river could be passed out through the section.

Such currents do not, however, in all probability, exist for long at a time, and the calculation stands in no certain relation to the actual conditions: it will nevertheless serve to show that in- and outflowing currents of the same order of magnitude as those measured would suffice to maintain the distribution of salinity as found.

Stronger currents are occasioned by the wind, this giving rise to both in- and outflowing movements simultaneously, and there can be no doubt that the heavy storms which are of so frequent occurrence form the principal factor in the renewal of the water in the fjord, this being effected partly by the currents mentioned, and partly through the mixing of adjacent water masses by the action of waves and breakers.

No further investigation as to the relation between wind and current was, however, made.

It now remains to consider the movements occasioned by changes in the water level of the fjord.

As will be shown in the following section, these have their origin partly in the action of the tide, and partly in barometric conditions, the wind, on the other hand, exerting practically no influence on the water level in the fjord. As barometric changes take place but slowly, it follows that tidal conditions must be those which mainly give rise to currents of the nature here referred to.

Taking the difference between highest and lowest water as 1 metre, which figure can, approximately, be attained, we may now proceed to calculate, as nearly as possible, what current would be required at the outer part of the fjord in a section from Høvda Point across the grounds at Skarvetange in order to permit of such change in the water level as assumed.

The area of the section referred to, which lies in the vicinity of Station 18 (Fig. 1) is 5×10^4 m^2, and the area of the fjord up to this section 7.3×10^6 m^2. If then, in the course of 6.2 hours, the water

level is to vary 1 metre, then the maximal value of the current will be 2 cm/sec., being taken as varying according to a sine function, and as constant for all points of the section.

As this action of the tide must gradually decrease towards the base of the fjord, it is unlikely that it should be of any great importance as regards the mixing of water in the fjord.

Apart from this, however, the tidal currents outside the fjord are, as we know, of very considerable strength, and it is possible that there may be currents in the fjord owing their existence directly to these.

An attempt at discovering the presence of such currents by noting corresponding alterations in the salinity farther up in the fjord has not, however, led to any result. The determinations of salinity from Station 12 made with this object in view are included in the observation material on p. 41.

3. Level of water in Trangisvaag Fjord. Tides. Influence of barometrical conditions.

During the period from 20 May to 16 June 1913, measurements of the water level were made at the stations marked A and B in Fig. 1.

At Station A, the outermost in the fjord, the measurements were made by the simple process of reading from a measuring board fixed to a landing stage. At Station B, the innermost, a vertical funnel, made of boards, and with an opening at the bottom, was fixed in the water. The height of the water in this funnel was taken by means of a float inside the same, having a tape measure attached, affording an easy and fairly accurate method of reading, all that was necessary being to lower the float until it was almost supported by the water, and the strain on the tape consequently reduced.

At both stations, measurements were taken at the hours of 8 a. m., 10 a. m., 12 noon, 2 p. m., 4 p. m. and 6 p. m.; and at Station B also at 8 p. m., the hours reckoned according to Greenwich time.

From the observations thus made, the amplitude and phase for the periods $(S_2 + K_2 + K_1)$, M_2, 2MS and O were found. The terms are those generally used, save only that $(S_2 + K_2 + K_1)$ indicates the period of 12 solar hours found in the mean values at 8 a. m., 10 a. m., 12 noon, 2 p. m., 4 p. m. and 6 p. m., the calculation of constants for this period giving values which comprise constants from S_2, K_2 and K_1. This is due partly to the fact that S_2 and K_2 are of so nearly identical periodic length that it is impossible to separate one from the other in so short series of observations as the present, and partly to the fact that the series from the two stations contained only observations from the daytime. We must therefore expect to find, in the mean values for the times given, a variation corresponding to one-half of an oscillation in the K_1 period, which variation will be included in the calculated values for amplitude and phase for the period $(S_2 + K_2 + K_1)$, with a periodic length of 12 hours.

In calculating the $\varkappa$-figures, the time for $(S_2 + K_2 + K_1)$ has been reckoned from 12 o'clock local time; for the other periods, from the culmination of the fictive star. The amplitude and $\varkappa$-figures are shown in table 2; R = difference between maximal water level for the period and mean level.

In calculating $(S_2 + K_2 + K_1)$ and 2MS, correction has been made for the period occasioned in the mean values formed by the influence of the M_2 period.

The amplitudes for the M_2 and O periods in the table are referred to the mean value for the inclination in the orbit of the moon.

In addition to the periods noted in the table, N, M_4 and MS were also calculated; for these, however, only amplitudes of 1 to 2 cm were found, and they could thus not be considered as sufficiently accurately determined from the material available.

Table 2. Harmonic Constants for Water level in Tangisvaag Fjord.

Period	Station A		Station B	
	R	$\varkappa$	R	$\varkappa$
$(S_2 + K_2 + K_1)$	10,3	166	9,8	166
M_2	22,2	180	25,2	177
2 M S	3,6	95	2,6	81
O	6,3	190	4,4	151

In the constants noted for the first period ($S_2 + K_2 + K_1$) the portion originating from the S_2 period is doubtless the largest. The ratio between the theoretic values of the amplitudes is, for $S_2 : K_2 : K_1 = 1.00 : 0.27 : 1.25$, but whereas the ratio between the amplitudes for K_2 and S_2 in the North Atlantic and adjacent waters generally possesses its theoretic value, the ratio between the amplitude for the period K_1 and that for S_2 is considerably — often several times — smaller than the ratio between the corresponding forces.

For Thorshavn, CRONE [1]) has found the harmonic constants for water level here given in Table 3.

Table 3. Harmonic Constants for Water Level in Thorshavn (from CRONE).

S_2		K_2		K_1		M_2		2 M S		O	
R	$\varkappa$	R	$\varkappa$	R	$\varkappa$	R	$\varkappa$	R	$\varkappa$	R	$\varkappa$
5,6	204	0,9	197	4,3	135	10,4	187	0,5	90	7,3	46

A comparison between the constants for Thorshavn and those above found for Trangisvaag shows, that M_2 is in both places the most pronounced period. The phase is in both places about the same; the amplitude found for Trangisvaag is, however nearly twice as great as that for Thorshavn. As regards the 2MS period, the fact that the phase for this has been found to be approximately the same at both places, whereas the amplitude is greater for Trangisvaag than for Thorshavn, is of minor importance, owing to the slight magnitude of the amplitudes. On the other hand, the great difference in the phases for the O period is very striking.

By calculating, from the constants given for Thorshavn, the contribution furnished by the periods S_2, K_2 and K_1, to the level of water on the 1st June 1913 at the hours of 7.30 a. m , 9.30 a. m. etc. local time, we obtain the values shown in the uppermost line of Table 4, reckoned from the mean value of the water level calculated from the six first figures.

Table 4.

Time	$7^1/_2$ a	$9^1/_2$ a	$11^1/_2$ a	$1^1/_2$ p	$3^1/_2$ p	$5^1/_2$ p	$7^1/_2$ p	R	$\varkappa$
Calculated water level *h* for Thorshavn	3.5	— 1.5	— 5.7	— 4.8	1.1	7.7	9.9	6.5	180
Mean value for Stat A	1.7	— 3.1	— 9.7	— 6.5	4.3	13.5		10.3	166
— — - — B	2.3	— 3.8	— 9.3	— 5.5	3.4	12.7	14.8	9.8	166
1.55 × *h*	5.4	— 2.3	— 8.8	— 7.4	1.7	11.8	15.2		

The table further shows the mean values of the observations at the hours 7.30, 9.30 etc. local time, for the two stations A and B, and it will be seen that these mean figures exhibit very nearly the same course as the values calculated for Thorshavn for the 1st June 1913, which forms about the centre of the series of observations.

If R and $\varkappa$ be calculated from the first six mean values, we obtain the values shown on the right of the table. In the lowest line of the table are given the figures obtained by multiplying the calculated water levels for Thorshavn by 1.55, this being the ratio between the values of R for Trangisvaag and Thorshavn. These show even more distinctly the similarity with the mean values for water level in Trangisvaag at the times noted.

[1]) C. CRONE: Flux et Réflux des Mers . . . etc. Institut météorologique de Danemark; Copenhague 1906.

As moreover, the phases for the two localities thus found agree sufficiently well one with another, it is reasonable to suppose that the periods in question for water level both in Trangisvaag and Thorshavn have the phases found by CRONE, but that the amplitudes for Trangisvaag are 1.55 times greater than in Thorshavn. We thus find, for Trangisvaag:

	S_2	K_2	K_1
R.....	8.7	1.4	6.7
$\varkappa$.....	204	197	137

A remarkable feature however, is the high value for the amplitude for the K_1 period.

By way of illustrating the variation in water level at the different phases of the moon, this has been shown in Fig. 7. The actual water levels are marked on the figures, together with a curve indicating the variation in water level calculated from the periods obtained ($S_2 + K_2 + K_1$), M_2, O and 2 MS. For the hours of 5.30 p. m. and 7.30 p. m. on the 28th May, interpolations have been made from the measurements of water level at the corresponding hours on the day preceding and that following, the observations actually made in these two instances being evidently erroneous.

Daily variation of water level in Trangisvaag, compared with phases of the moon.

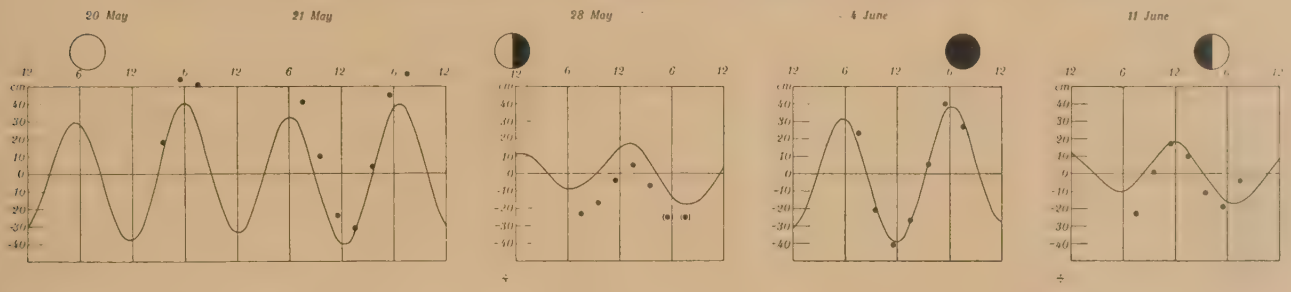


Fig. 7. The points denote water level as observed at Station B, the innermost station in the fjord, calculated from mean water level based on the whole of the observation material from 20 May to 16 June. The drawn curves are obtained from the constants given in Table 2. An approximately constant difference should be expected to appear between the points denoting actual water level as measured and the corresponding points on the curves, the water level in the fjord on the days in question having been comparatively high or low.

To facilitate investigation of the variation in the mean water levels from day to day, these have been included in Table 5 for Stations A and B, the figures being obtained by formation of mean values from the actual observations made at the hours of 8 a. m., 10 a. m., 12 noon, 2 p. m., 4 p. m. and 6 p. m. Greenwich, these mean values being corrected for the error occasioned by the fact that only about half the oscillations in the O period are included in the formation of mean values; as also for the error arising from the fact that the 6 observations above mentioned do not cover a whole oscillation of the M_2 period.

The values thus corrected are calculated from the mean value of the water level for the whole of the time under consideration.

For purposes of comparison with the daily mean values for the water level, the difference δ between the mean value of the barometer level at Thorshavn at the hours of 7 a. m., 2 p. m. and 5 p. m. Greenwich [1]) and a mean value for the barometer level for the whole of the time have been noted in the table.

By multiplying the daily mean figures for the difference δ by the specific gravity of the mercury. 13.6, and comparing the figures thus obtained with the mean values for water level Δ_A und Δ_B it will

[1]) Wetterberichte 1913.

be seen that the sums $\Delta_A + 13.6\,\delta$ and $\Delta_B + 13.6\,\delta$ exhibit considerably lower numerical values than the mean values for the water level, in addition to which the values in question present a regular periodic variation.

The length of this period is very nearly = 14 days, and while the material is insufficient to furnish any demonstration of the different periods of longer duration in the tidal movement, we may nevertheless naturally take the period found as standing in some relation to the periods of 14 days occasioned by the movement of the moon, especially as it would seem impossible to explain them in any other way. Taking the periodic length of variation in $\Delta_A + 13.6\,\delta$ and $\Delta_B + 13.6\,\delta$ as 13.66 solar days, which is the length of the tropical half-monthly period, these values can be expressed by

$$p = 8 \cos (26^0,4\ t - 108^0)$$

t being measured in solar days, and calculated from 1st June 1914, 12 noon local time. The amplitude and phase of the function are determined by graphic smoothing.

Finally, in the columns marked $\Delta_A + 13.6\,d - p$ and $\Delta_B + 13.6\,\delta - p$ are noted the figures calculated from these expressions, which only exhibit so small values that their deviation from zero may be explained as due to inaccuracy of measurements.

The two last columns of the table give the mean values for the wind components in the directions N and E, based on observations made at the hours 7 a. m., 3 p. m. and 5 p. m. Greenwich time for Thorshavn.

Table 5.

Month	Date	Water level at Stat. A. Δ_A cm	Water level at Stat. B. Δ_B cm	Barometer level at Thorshavn δ m/m	$\delta \cdot 13{,}6$	$\Delta_A + 13{,}6\,\delta$	$\Delta_B + 13{,}6\,\delta$	$p = 8\cos(26^0{,}4\,t - 108^0)$	$\Delta_A + 13{,}6\,\delta - p$	$\Delta_B + 13{,}6\,\delta - p$	Thorshavn Wind-components	
											towards N 0—12	towards E 0—12
May	21	9	11	— 2.7	— 4	5	7	6	— 1	1	1	— 2
	22	15	14	— 2.7	— 4	11	10	8	3	2	2	0
	23	8	8	— 0.9	— 1	7	7	8	— 1	— 1	0	4
	24	— 4	— 6	7.7	10	6	4	6	0	— 2	1	3
	25	— 2	— 1	2.1	3	1	2	3	— 2	— 1	2	3
	26	— 7	— 6	4.1	6	— 1	0	— 1	0	1	0	6
	27	— 16	— 18	9.2	13	— 3	— 5	— 4	1	— 1	1	3
	28	— 11	— 10	5.0	7	— 4	— 3	— 7	3	4	1	— 2
	29	— 5	— 5	— 2.9	— 4	— 9	— 9	— 8	— 1	— 1	2	2
	30	0	— 1	— 0.9	— 1	— 1	— 2	— 8	7	6	— 1	— 1
	31	9	6	— 10.7	— 15	— 6	— 9	— 6	0	— 3	2	0
June	1	— 3	— 7	— 0.1	0	— 3	— 7	— 2	— 1	— 5	1	3
	2	— 2	0	— 1.8	— 2	— 4	— 2	1	— 5	— 3	4	— 2
	3	8	9	— 3.5	— 5	3	4	5	— 2	— 1	1	4
	4	1	1	4.1	6	7	7	7	0	0	1	2
	5	11	11	— 0.3	0	11	11	8	3	3	1	1
	6	11	11	— 2.7	— 4	7	7	7	0	0	1	1
	7	24	24	— 13.9	— 19	5	5	5	0	0	2	0
	8	...	16	— 11.0	— 15	. .	1	2	...	— 1	— 3	0
	9	3	5	— 6.0	— 8	— 5	— 3	— 2	— 3	— 1	0	— 1
	10	6	6	— 7.6	— 10	— 4	— 4	— 4	0	0	— 5	0
	11	— 2	— 5	0.2	0	— 2	— 5	— 7	5	2	— 1	0
	12	— 12	— 14	6.5	9	— 3	— 5	— 8	5	3	— 2	0
	13	— 22	— 22	11.4	16	— 6	— 6	— 7	1	1	3	3
	14	— 13	— 12	7.7	10	— 3	— 2	— 5	2	3	3	3
	15	...	— 12	9.2	13	...	1	— 1	...	2	4	2

The mean values are simply formed from the values noted from the 0—12 scale.

It will be seen that no connection can be shown to exist between these mean values for the wind and the figures recorded under $\Delta_A + 13.6\,\delta - p$ and $\Delta_B + 13.6\,\delta - p$, nor can the 14 days' period found be seen to be dependent in any degree upon the wind.

Daily mean water level in Trangisvaag compared with level of barometer.

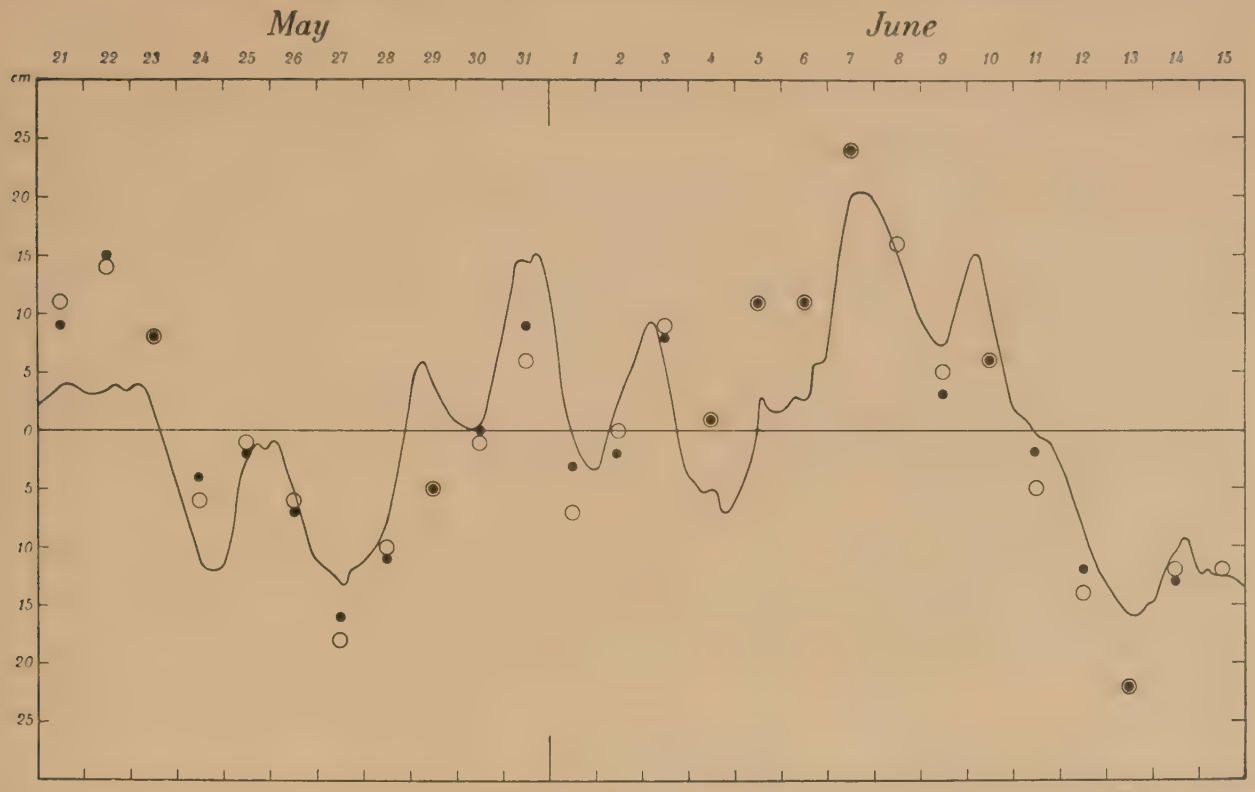


Fig. 8. The points • and o denote the daily mean water levels for the two stations A and B respectively in Trangisvaag. The daily mean water levels are calculated from a mean value for the whole period from 21 May to 15 June as zero. The drawn curve shows the function — 13.6 δ, where δ is the deviation of the barometer level from a mean value for the whole of the period.

Daily mean water level in Trangisvaag as compared with a value for the same calculated from the barometer level and a period of 14 days in the water level.

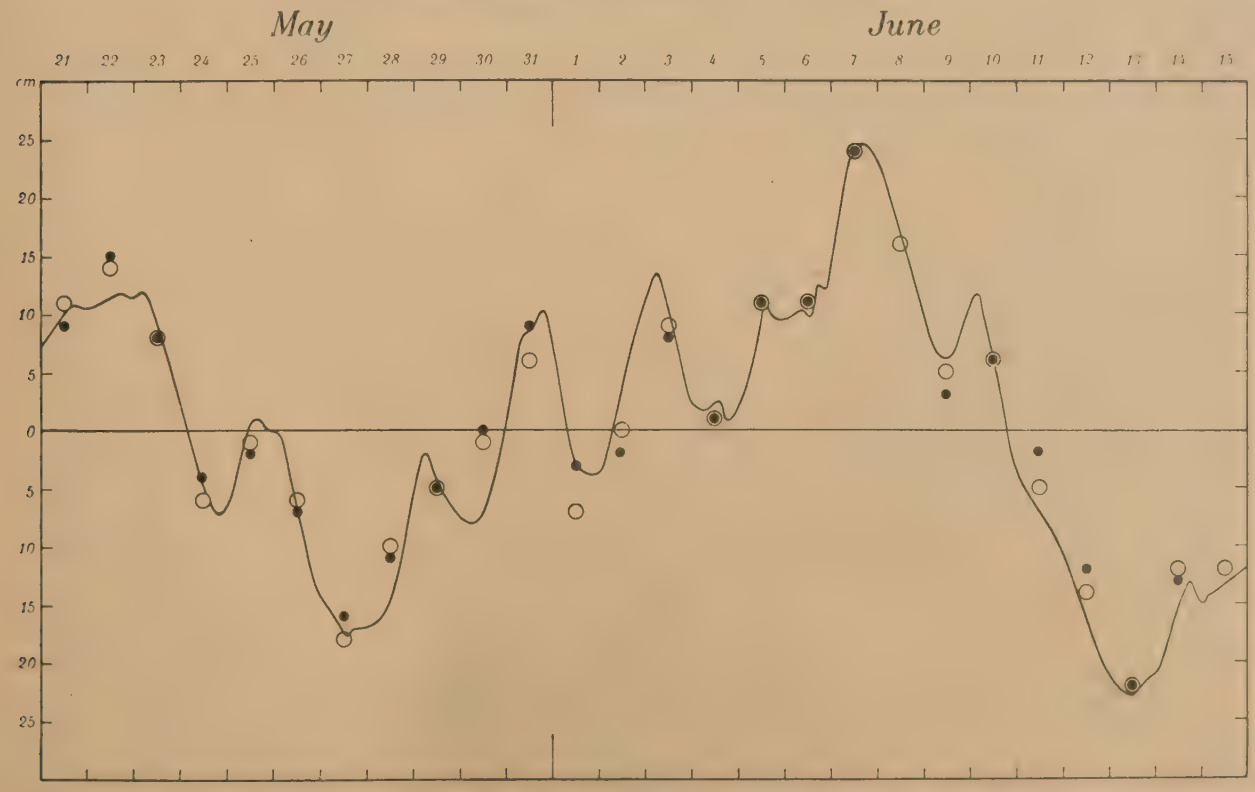


Fig. 9. The points • and o denote the daily mean water levels for the two stations A and B respectively in Trangisvaag Fjord. The daily mean values are calculated from a mean value for the whole period from 21 May to 15 June. The drawn curve shows the function $-13.6\,\delta + 8\cos(26^{\circ},4\,t - 108^{\circ})$, where δ is the deviation of the barometer level from a mean value for the whole period, and t the number of days having elapsed since 12 o'clock local time on the 1st June 1913.

It must therefore be presumed that under the prevailing conditions, the wind has not exerted any influence upon the level of the water.

A graphical illustration of the daily mean water level in relation to the barometer level will be found in Fig. 8, where the water levels observed are marked by points, the ordinates of the curve indicating the function $-13.6\,\delta$. δ being the deviation of the barometer level from the mean value.

Finally, in Fig. 9, a comparison is shown between the water levels observed, in the same manner as in Fig. 8, and the values calculated from the function $-13.6\,\delta + 8\cos(26^0{,}4\,t - 108^0)$, the curve indicating the function.

From Figs. 8 and 9, as also from Table 5, it is evident that during the time embraced by the measurements, changes in the barometer level have been the main causes of alterations in the daily mean level of the water.

As Trangisvaag Fjord is so directly connected with the open ocean, this must be considered as generally applicable to the whole area of sea about the Færoes. It is possible that a longer series of observations, extending say over a whole year, might bring to light changes in the water level which cannot be explained as due to alterations in the barometer level. In order to determine how far this may be the case, a greater amount of observation material would be required.

II. Investigations on the Færoe Bank and in adjacent waters.

Current measurements on the Færoe Bank.

The results of the measurements of temperature and salinity from the cruise of the »Margrethe« are published in the »Bulletin hydrographique« 1912—1913, and it will hardly be necessary to reprint the material here. In the investigation as to mixing of sea water on the banks and in the deeper waters outside this will later (Section III) be dealt with together with the observation material obtained from here and from other banks on previous occasions. A short series of current measurements was made on the Færoe Bank, the results of which are given below.

At a station on the Bank (Lat. 60° 59′ N, long. 8° 20′ W) a buoy was laid out. Four inflated canvas bags of the kind generally employed were fastened to the anchoring line behind the buoy, which was furnished with a twelve-foot pole having a flag at the top.

For measurement of the current, the floats mentioned on p. 10 were used, one being arranged for surface measurements, as in Trangisvaag Fjord, the other for work at 50 metres depth, the line between the canvas cylinders and the bottle being in this case 50 metres long.

When measuring, the ship was sailed close by the anchored buoy, and the two floats cast at the moment of passing. The vessel was then so handled as to remain constantly in the vicinity of the two floats, and after the lapse of 10 to 15 minutes passed close by them, one by one. At the moment of passing either float, the angular elevation of the pole on the buoy was taken by sextant, and bearings for direction by compass.

In this manner, 8 measurements of the surface current, and 8 of that at 50 metres depth were made in the course of $9^1/_2$ hours; on the following day four more current measurements were made.

On the first day, the weather was quite calm, and the water mooth. On the second day, a breeze came up from the SW, attaining a force of 6 m/sec while the measurements were still in progress. Judging from my experience on this occasion, I am convinced that with a well equipped vessel, current

measurements could be made in this manner during any weather not so violent as to preclude all possibility of making hydrographical investigations at all. Fog might of course prove a serious obstacle, if so dense as to render the buoys invisible.

When making current measurements in this manner in deep water, it will be advisable to use a thin wire or piano string for connecting float and cylinder. It is possible to correct the measurements for effect of current on the wire, when measurements are taken simultaneously at different depths. The method may be improved by employing Zeiss' stereotelemeter for measuring the distances.

The measurements were made on the 12th and 13th June. The results are shown in Table 6.

Table 6. Current measurements on the Faeroe Bank.
60° 59' N Lat. 8° 20' W Long. Depth ca. 110 m.

Time at place	0 m		50 m	
	Direction towards	Force cm/sec	Direction towards	Force cm/sec
1913. VI 12; 11^h28 — 11^h38 a. m.	N	58	N	58
» » » 12^h19 — 12^h29 p. m.	N 11 E	53	. . .	. . .
» » » 12^h19 — 12^h36 » »	N 22 E	46	N 22 E	49
» » » 2^h00 — 2^h11 » »	N 68 E	70	N 68 E	68
» » » 3^h51 — 4^h02 » »	S 67 E	84	S 67 E	77
» » » 5^h21 — 5^h32 » »	S 45 E	75	S 33 E	63
» » » 7^h58 — 8^h06 » »	S 34 W	109	S 34 W	87
» » » 8^h58 — 9^h09 » »	S 56 W	127	S 56 W	95
» » 13; 6^h28 — 6^h39 a. m.	S 45 W	30	. . .	. . .
» » » 7^h07 — 7^h30 » »	S 68 W	32	S 68 W	35
» » » 1^h30 — 1^h45 p. m.	. . .	. . .	N 23 E	57
» » » 1^h30 — 2^h13 » »	. . .	. . .	N 34 E	62

During the measurements on June 12 there was no wind. At 6^h 30 a. m. on June 13 the wind came from SW blowing 2 m/sec. At 1^h 30 p. m. the wind wind was SW 6 m/sec.

Figs. 10 a and 10 b give graphical illustrations of the currents as measured. The largest points on the figures indicate that the direction and velocity of the current at the times there noted were as shown by lines drawn from the initial point to the points in question.

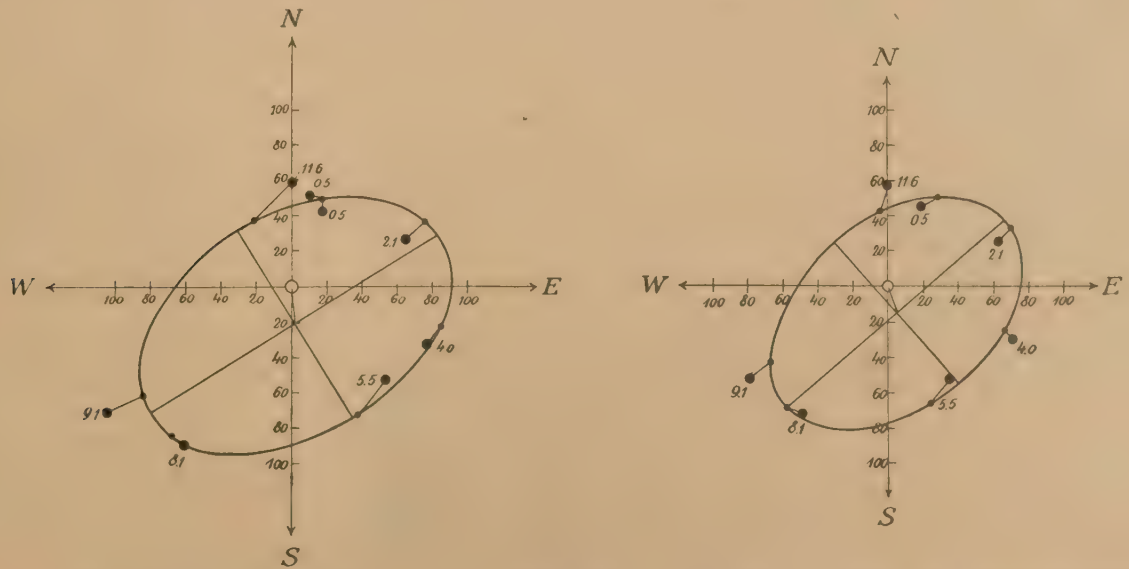


Fig. 10 a and 10 b. If lines be drawn from zero to the largest points, then the lines in question will indicate the velocity and direction of the currents observed at the times noted. The smaller points on the ellipse have been obtained by smoothing; lines drawn from zero to these will denote the smoothed values for velocity and direction of the current.

It will be noticed that during the time occupied by the measurements, the current changed its direction in such a manner as to suggest tidal movement as the principal cause of such change. I have therefore calculated the tidal ellipse on the basis of measurements from the 12th June, presuming the existence of a constant current in addition to the tidal current.

Table 7 shows the characteristic velocities for the tidal current, obtained from the calculation.

Table 7.

	0 metres	50 metres
Direction of constant current towards	S 7 E	S 16 E
Force » » » cm/sec	22	16
Half of the major axis of the tidal ellipse cm/sec	96	82
» » » minor » » » » » »	64	53
Direction of the major axis of the tidal ellipse	N 58 E	N 51 E
Time when the tidal current sets in direction of major axis N 58 E and N 51 E respectively	2^h30	2^h00

From the facts thus ascertained, it would seem that the tidal currents on the Færoe Bank are very strong, and in view of the calmness of the weather at the time of measurement, it appears probable that disturbing influences from other causes of current in the sea have been but slight.

The measurements from the 13th June have not been included in calculation of the ellipse, as the wind had then commenced to make itself felt; it will be seen from Table 6, that the values found in the morning do not agree with what might have been expected from the measurements of the 12th; the figures for 1.30 p. m. to 2.13 p. m., however, fit in very well with these.

Even though the tidal currents here found do in all probability agree with actual conditions, it would yet be highly desirable to have other measurements of this nature carried out for purposes of comparison. Such measurements would, moreover, be especially valuable if made in such a manner as to render it possible to determine how the tidal currents varied with the age of the moon.

From the present single series of measurements it is impossible to determine how the tidal current thus found is composed from the currents corresponding to the different tidal periods, especially M_2 and S_2; it may, however, be noted that the measurements were made very near the moon's first quarter, which occurred on the 11th of June, and that the currents at new and full moon probably exceed the values here measured. As will be seen from Fig. 7, the variation of the water level in Trangisvaag Fjord was considerably less on the 28th May and 11th June when the moon was in quadratures, than at new and full moon on the 20th May and 4th June.

Helland-Hansen [1]) made some current measurements on the Rockall Plateau on the 7th and 8th July 1913, or very nearly a month after those here made on the Færoe Bank, and consequently in approximately the same phase of the moon as these. The Rockall Bank currents show, on the whole, velocities only about $^1/_5$ of those found on the Færoe Bank.

III. Mixing of sea water on banks in the North Atlantic. Currents in the Færoe-Shetland Channel.

As shown in the foregoing section, the currents on the Færoe Bank are very strong, and it will therefore be reasonable to investigate how far their effects are apparent in the distribution of temperature and salinity.

[1]) Bjørn Helland-Hansen: Atlanterhavstogtet med »Armauer-Hansen«, Sommeren 1913. Naturen, Oct. 1913.

Paulsen [1]) and Schmidt [2]) have already found that the surface temperature and salinity on the Færoe and Rockall banks during the spring months are somewhat lower than in the adjacent area of the sea, which phenomenon has been dealt with by Martin Knudsen [3]) on the basis of these and other observations.

When carrying out the hydrographical investigations on board the »Margrethe«, I also directed my attention towards the investigation of this phenomenon; the material obtained was, however, owing to existing conditions, smaller than was desirable. In order to procure a broader foundation, therefore, I have taken material from hydrographical stations in these waters published in the Bulletin trimestriel etc. from the commencement of the International Investigation of the Sea. The greater part of this material has been collected from Scotland; a considerable portion, however, also by Danish investigators.

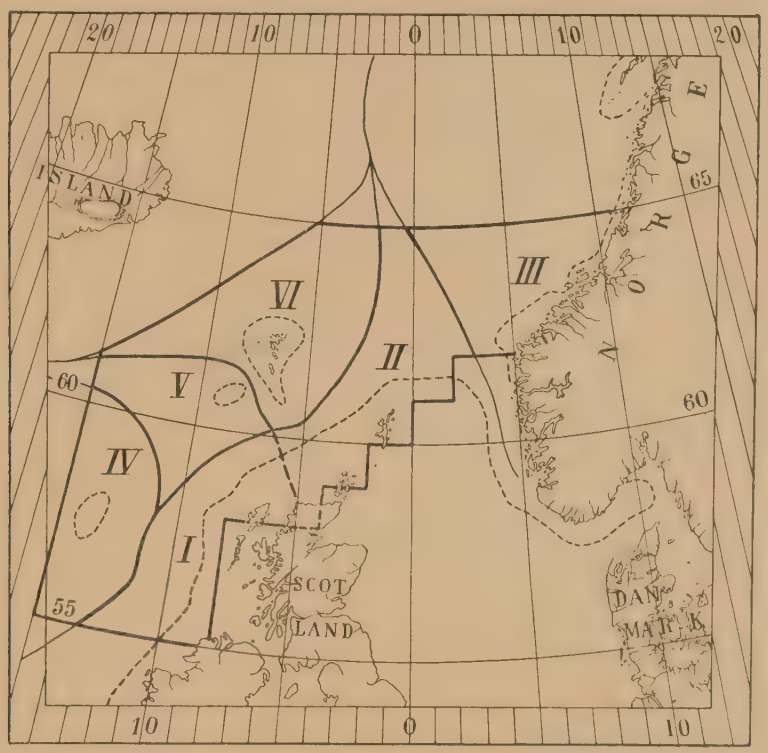


Fig. 11.

The whole of the region from which the observation material has been taken in consideration was divided into 6 areas, the boundaries of which will be seen in Fig. 11. These limits have been drawn, partly through the deepest parts which intervene between shallower grounds, and partly along certain degrees of latitude and longitude, indicated in the figure by thick lines. Within each of these areas, which are numbered I—VI, are the hydrographical stations, arranged in small groups, with depths $<$ 100, 100—125, 125—150, 150—200 and $>$ 200 metres respectively. Within these groups again, the stations are arranged according to months, while for each month, mean figures have been worked out from the values for temperature and salinity at 100 metres depth, as also mean figures for difference in temperature and salinity at 50 and 100 metres. The results are given in Table 8, where t and s indicate the mean figures

[1]) Ove Paulsen: Plankton Investigations etc. Medd. fra Komm. for Havunders. Ser. Plankt. I. 8 p. 30. København 1909.
[2]) Johs. Schmidt: The distribution of the pelagic fry etc. Conseil perm. internat. Rapp. et Proc. verb. Vol. 10, p. 221. Copenhagen 1909.
[3]) Martin Knudsen: Danish hydrographical investigations at the Færoe Islands in the spring of 1910. Medd. fra Komm. for Havunders. II. 1. København 1911.

Table 8.

Month	Depth in the Sea	I					II					III					IV					V					VI				
		t	s	Δt	Δs	n	t	s	Δt	Δs	n	t	s	Δt	Δs	n	t	s	Δt	Δs	n	t	s	Δt	Δs	n	t	s	Δt	Δs	n
February	<100	7.65	17	1	0	1																									
	100—125						6.56	22	4	0	2																				
	125—150						7.65	30	−1	0	2																				
	150—200						8.39	32	−1	0	1																				
	>200																														
March	<100																														
	100—125						6.64	25	−5	1	4																				
	125—150						6.85	26	15	−7	1																				
	150—200						7.13	29	7	−1	4																				
	>200						6.78	24	4	0	8	6.96	21	−8	−2	1															
April	<100																														
	100—125						6.63	29	13	1	3																6.30	16	1	−2	1
	125—150						7.17	32	34	0	3																6.59	25	1	0	1
	150—200						7.41	27	4	0	7																6.72	21	4	0	1
	>200						7.60	28	8	1	12																7.33	24	8	1	8
May	<100						7.77	24	6	−2	2																				
	100—125						7.32	27	15	−2	8						8.60	21	10	0	1	7.94	26	1	−1	4	6.76	20	1	0	7
	125—150	9.90	35	50	0	1	7.84	28	29	0	15											8.18	28	7	0	3	6.91	18	1	0	7
	150—200						8.24	30	15	1	6						8.35	24	85	−3	2	8.43	28	10	0	3	6.76	18	26	0	6
	>200	9.70	34	60	1	1	7.95	25	33	2	71						9.40	30	32	2	4	7.86	26	12	1	5	7.18	23	35	2	44
June	<100						8.42	20	2	0	4																8.20	20	0	0	2
	100—125						7.70	25	28	1	6											8.65	26	1	−1	4	7.46	19	0	3	2
	125—150	8.31	26	10	−8	1	8.03	24	45	−1	4											8.37	26	8	0	1	7.27	18	9	0	6
	150—200						8.54	32	33	0	7																7.17	21	88	1	6
	>200	9.43	35	107	0	1	8.22	30	52	0	16	7.76	23	40	−2	7						8.63	30	46	−2	2	7.49	22	64	1	22
July	<100						8.72	27	20	−1	2																				
	100—125	8.46	26	145	0	3	8.27	27	94	−3	3																				
	125—150						8.69	26	79	3	3																8.00	21	15	−1	4
	150—200	9.37	35	74	2	1	8.86	34	81	0	6																				
	>200	8.73	35	61	0	2	8.64	27	69	−1	8																7.81	22	71	0	8
August	<100						9.90	27	48	−5	9																				
	100—125	9.21	17	289	0	1	9.19	25	67	−1	13																9.24	16	9	1	3
	125—150	9.54	26	117	−2	2	9.14	29	163	−1	10																8.73	20	27	−2	8
	150—200	9.62	28	123	−3	1	9.37	31	155	−2	5																7.80	18	151	−1	5
	>200	9.60	31	113	−1	15	8.87	30	98	−2	32											9.00	28	181	−3	5	8.19	24	111	−2	49
Septbr.	<100						11.91	12	0	0	1																				
	100—125						9.79	22	94	1	4																				
	125—150						9.51	25	126	−1	6																				
	150—200						9.82	28	152	0	2																				
	>200	9.75	26	182	−1	6	9.04	30	98	−2	11																8.76	18	115	0	2
Octbr.	<100																														
	100—125																														
	125—150						10.74	19	3	2	1																				
	150—200																														
	>200																														
Novbr.	<100						8.89	18	0	0	2																				
	100—125	10.67	26	197	−9	1	9.50	23	9	−2	5																8.76	19	4	0	1
	125—150						9.38	20	0	−2	5																9.02	10	−1	0	1
	150—200						9.08	26	−2	0	3																7.48	17	−1	0	4
	<200						9.20	27	7	−2	12																8.68	25	10	−3	8

for temperature and salinity at 100 m, Δt and Δs denoting respectively $t_{50} - t_{100}$ and $s_{50} - s_{100}$, the index marking depth. For values of s, only the decimals after the point have been included, the whole number ‰ being in all cases 35. Δt and Δs are noted with 0,01 ° and 0,01 ‰ respectively as unit. Under n is shown the number of observations employed in working out the mean figures.

At those groups of stations where depth was less than 100 metres, extrapolation has been made for temperature and salinity at 100 metres, stations of less than 90 m being, however, not generally included. In the case of a number of stations, e. g. most of the Scottish, it has been necessary to interpolate for temperature and salinity at 50 metres depth, the measurements having been taken at 40 and 60 m.

Finally, the whole material has been subjected to one restriction; viz: the exclusion of all stations where salinity at 50 or 100 metres depth did not reach 35.10 ‰. This was the case at a number of stations near the Scottish coast, and at a number of Norwegian stations in Area III.

It will be seen that by far the greater number of observations fall within the areas II and VI.

The object of the present investigation was to ascertain how far any difference could be shown to exist in the intensity of mixing at different places; hence the division into groups. It will be seen, however, that the mean values for temperature and salinity in the different areas exhibit characteristic differences, which must be due to the current movements which occur in this part of the Atlantic, and it will doubtless be most opportune to glance first at these in order to obtain an idea as to the main movement of the water.

The temperature at 100 metres presents a distinct annual course; in the case of the salinity, however, this is at any rate not immediately noticeable, and even though such may possibly exist, the observation material is too uncertain to permit of its being demonstrated. I therefore prefer to form mean values for the various groups in the different areas without regard to the time of year at which the observations were taken.

We thus obtain the values noted under S in Table 9; as in Table 8, only the decimals after the point are here noted under S. Under n are shown the numbers of observations from which the mean figures were calculated.

Table 9.

Depth to bottom	I		II		III		IV		V		VI	
	S	n	S	n	S	n	S	n	S	n	S	n
<100	17	1	24	20							20	2
100—125	24	5	25	27			21	1	26	8	21	14
125—150	28	4	27	50					28	4	19	27
150—200	32	2	29	41			24	2	29	3	19	22
>200	31	25	27	170	23	8	29	3	27	12	23	141

A glance at the stations indicated in Table 9 as lying outside the 200 metre line will show that the salinity at 100 m decreases from I. to II and thence to III; the same applies for IV to V and thence to VI.

It is more remarkable, however, that in Area II we find the maximum salinity for 100 metres depth at stations between 150—200 metres bottom depth, and that Area VI has the minimum salinity for 100 metres depth at stations between 125 and 200 m bottom depth. This can scarcely be accidental, and seems to suggest that the northerly movement of the salt water in Area II keeps particularly to that zone of the continental shelf where the depth lies between 150 and 200 metres, and that similarly, in Area VI, a southerly movement of the water from the

Norwegian Sea takes place at similar depths. In this connection it may be mentioned, that most of the stations employed lie in the eastern part of Area VI.

This supposed movement of the water agrees well with the conditions of temperature in the different months, the temperature at 100 metres depth being, as a rule greatest, at stations with depth between 150 and 200 metres in Areas I and II, and generally lower at such stations than at the adjacent stations in Area VI.

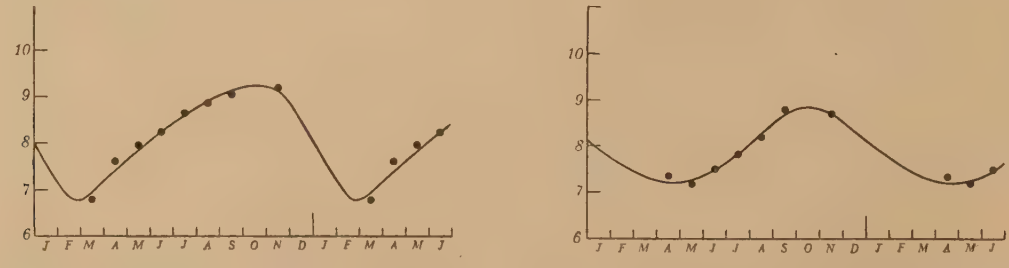
In Table 8, the temperatures to which this applies are underlined; it will be noticed that the rule does not, however, generally apply to the month of April, which forms an exception both in Area II and Area VI, nor to November, which constitutes a similar exception in Area II. As to how far this may or may not be accidental can hardly be decided from the material at present available.

If we compare the 100 metre temperatures in Areas II and VI for those stations which lie outside the 200 metre line, it will be found that these are, during the spring and summer months, higher for Area II than for Area VI. The difference may be seen from the following:

April	May	June	July	August	September	October	November
0.27	0.77	0.73	0.83	0.68	0.28		0.52

Bearing in mind that the great majority of the stations employed in Area VI lie on the eastern shelf of the Færoe Plateau, it will thus be seen that the difference in the mean values of the 100 m temperature outside the 200 m line in the waters between the Færoes and the Shetlands is greatest in the month of July, when it is 0.83° greater in the eastern than in the western part of that water.

The fact that the difference in temperature referred to rises, as shown in the table, in the course of spring and early summer is naturally explained by the movement of the water, since it must be presumed that there exists, also outside the 200 metre line, a northerly movement of the water at 100 metres depth near the coast of Scotland, and a southerly movement near the Færoes, the current being, however, strongest within a zone of the bank where the depth is between 150—200 metres.



Figs. 12 a and 12 b. Fig. 12 a shows the annual course of the temperature at 100 metres depth at stations with depth exceeding 200 metres situated in Area II (*vide* Fig. 11), Fig. 12 b showing the same for Area VI.

Figs. 12 a and 12 b give a graphical illustration of the 100 m temperature for stations outside the 200 m line in Areas II and VI respectively, for the different months of the year. Even though the material is not as complete as might be desired, it yet serves to give a very good idea as to the annual course of the temperature.

The maximal temperatures at 100 metres 9.2 for Area II and 8.8 for Area VI both occur about the beginning or middle of October. The annual mean temperature at 100 metres must in both places be very nearly the same; viz: 8.0.

By way of comparison with the annual course of the temperature at 100 metres depth as here

given, it may be mentioned that according to MARTIN KNUDSEN [1]), the surface temperature t at the Scottish station Sc. 22, situate at lat. 59° 36′ N, long. 0° 41′ W, is expressed by the formula $t = 9.1 + 2.8 \sin(\tau - 141)$, τ indicating the number of days after 1st January. The formula gives maximal temperature at this station as 11°.9, occurring about the end of August.

In order to further obtain an idea as to the annual variation of the 100 m temperature at stations situated in other subdivisions of Areas II and VI, with less than 200 m depth, I have noted, in Table 10, the differences between the 100 metre temperature in these subdivisions and the 100 m temperature in that subdivision where the depth exceeds 200 metres. The figures are given in hundredths of a degree.

Table 10.

Depth to bottom	Area II												Area VI											
	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
<100					— 2	20	8	103	287		— 31													
100—125			— 14	— 97	— 43	— 52	— 37	32	75		29					— 103	— 42	— 3		105			8	
125—150			7	— 43	5	— 19	5	27	47		18					— 74	— 27	— 22		54			34	
150—200			35	— 17	45	32	22	50	78		— 12					— 61	— 42	— 32		— 39			— 120	

As already mentioned, it will be seen that the 100 metre temperature for stations with depths between 150 and 200 metres in Area II is, with few exceptions, higher than the 100 metre temperature for stations with depth exceeding 200 metres, whereas the reverse is the case in Area VI.

For stations with depths less than 150 metres, it will be seen that the 100 metre temperature is lower in the spring months and higher in the summer months than the 100 metre temperature at stations with depth exceeding 200 metres. The annual amplitude for the 100 metre temperature is evidently greater for those stations which lie nearer to land than for those situated in deeper water; the material is, however, somewhat small for closer investigation of the annual variation in temperature.

In connection with the views herein advanced as to conditions of current between the Færoes and the Shetlands, it may be mentioned that NANSEN and HELLAND-HANSEN have previously arrived at similar results. In regard to this question, reference may be made to NANSEN's latest publication on the subject [2]).

As we have seen, and as has also earlier been pointed out by various hydrographers — among Danish writers by MARTIN KNUDSEN and J. N. NIELSEN — it is possible to indicate with some degree of certainty the mean movement of the sea water in the regions here concerned. After what has been stated in the foregoing, however, as to the backward and forward currents on the Færoe Bank in connection with the hydrographical conditions found by PAULSEN and SCHMIDT, it appeared to me as a point of essential importance to investigate the mixing of water layers, both on the banks and over greater depths, by way of supplement to the investigation of the translatory movements of the water.

With this object in view, the available observation material was arranged in the manner already described.

Table 8 shows, as already mentioned, under Δt, mean figures for the differences in temperature, stated in hundredths of degrees, for 50 and 100 metres depth at the different groups of stations, and similarly, under Δs, the differences in salinity, stated in hundredths $^0/_{00}$.

Glancing first at the differences in salinity, Δs, it will be understood that the mixing of the water is probably considerable, since all the differences are of small magnitude; so small, indeed, that they

[1]) Supplement to the Bulletin trimestriel. 1906—1907.

[2]) F. NANSEN: The waters of the north-eastern North Atlantic. Intern. Revue etc., 1913, p. 109.

may be presumed to be due to errors in observation, or to accidental circumstances impossible to explain.

It is otherwise with the differences in temperature. During those months when the heating of the water takes place, it is evident that they are lowest at those stations where the depth is least. Stations with depth exceeding 200 metres exhibit as a rule the greatest difference in temperature, these being however, of the same order of magnitude as for stations with depth between 150—200 metres.

Although only very few observations are available for the winter months, we may doubtless presume that this difference in temperature between 50 and 100 metres depth is, at that time of the year, insignificant. It makes its appearance in May, and is most distinctly evident during the months of May, June, July and August, showing a continual increase for the stations outside the 200 metre line, and reaching in August values approaching 1^0; in all probability, this order of magnitude is maintained for some time after August, falling again, however, during the autumn months, to smaller values.

The greatest amount of material has been collected from Areas II and VI, and in these there is evidently an essential difference in the temperature variations for stations with depth less than 150 metres. Even though the difference in temperature for both areas be lowest at stations with least depth of water, the phenomenon is nevertheless far more distinctly evident in Area VI than in Area II. It will be seen that in Area VI, these differences of temperature are, during the months of May, June and July, so small in the case of stations with depth less than 150 metres, as to be equally attributable to errors of observation.

If we now proceed to consider the mean values found for temperature difference at 50 and 100 metres depth, in a single month, as a means of measuring the degree of mixing which has taken place in the water at those depths during the month in question, we find, from the foregoing, that:

1) The mixing at 50—100 metres depth at places where depth exceeds 200 metres is approximately the same for Scotland-Shetlands and the Færoes.

2) The mixing at 50—100 metres depth in places near Shetlands—N of Scotland where depth is less than 150 metres is considerably greater than in places with greater depth.

3) The mixing at 50—100 metres depth in places near the Færoes with depth less than 150 metres is quite remarkably intensive in comparison with that which takes place at localities of greater depth.

Although these results are arrived at on the basis of temperature observations made during early summer, there is nevertheless reason to believe that the same may likewise apply to the remainder of the year.

From the other areas, the material is, as already mentioned, somewhat scantier; nevertheless it will be seen that the conditions on the Færoe Bank (Area V) very nearly correspond to those prevailing at the Færoe Islands themselves (Area VI). From the Rockall Bank (Area IV) the material is so poor as to render it impossible to draw any certain conclusions with regard to conditions there; in all probability, however, the mixing there is somewhat less intensive than on the Færoe Bank and at the Færoes. As we have seen, the tidal currents are here considerably weaker than on the Færoe Bank, and these form, we may presume, an essential factor in the mixing process. A closer investigation of the tidal movement would, however, be desirable, also as regards the study of mixing processes.

Several hydrographers have noticed that the surface temperature and salinity of the water over banks in the north-eastern Atlantic were lower than in the adjacent waters, and the phenomenon has of recent years been discussed by NIELSEN [1]), KNUDSEN [2]) and NANSEN [3]). NIELSEN and NANSEN attribute it to convection currents from the winter cooling, and are of opinion that it is simply this winter water which lies on the banks. KNUDSEN suggests that currents and mixingprocesses occasion a raising of the colder and salter water, thus giving rise to the phenomenon in question.

After what has been stated in the foregoing, the peculiarity may be explained as due to the fact that the mixing on the banks is more intensive than in the adjacent waters, so that on such banks, it will be mainly water of lower salinity and temperature which comes to the surface at those seasons of the year when the phenomenon has been observed. There is thus nothing unnatural in its being noticed in the summer, when the water from the winter cooling would scarcely be found on the banks in any considerable quantity.

It has been remarked by biologists [4]) as a peculiar fact, that out in the ocean, on banks such as the Rockall and Færoe Banks, neritic plankton has been found, and also that cod spawn there. It would hardly be reasonable to take this as standing in any direct relation to the slight differences in temperature and salinity between the water on the banks and that of the localities outside; nevertheless it is worth while to note the features common both to the coastal area and the banks, viz:

1) the lesser distance to bottom.

2) the intensive mixing of the water.

It is possible that these common features tend to create similar conditions for the developement of organic life, the germs of such being presumably almost everywhere present, on account of the strong and often variable currents.

IV. General remarks on mixing of water in the sea.

In describing the conditions of movement of the water within a certain area of sea, it is as a rule only possible to give the principal features, whether with a view to indicating the mean character of such movement, or certain definite deviations from the same. Various movements must therefore be considered as of minor importance, and either be disregarded altogether, or but summarily treated.

Such summary treatment can, however, be effected in different ways, and it appears to me a point of importance to find some such expression for the same as may be employed for further dealing with hydrographical problems connected therewith.

The problem here to be solved may be formulated as follows:

Given any unit of volume, e. g. 1 ccm, at a certain place and time, to ascertain what fraction of the water found therein after the lapse of t seconds is derived from water in a unit of volume situated at any given spot in the surrounding water mass at the commencement of the time.

[1]) J. N. NIELSEN: Contribution to the Hydrography of the Northeastern part of the Atlantic Ocean, p. 12. Medd. fra Kom. for Havunders. Ser. Hydrogr. Bd. I, Nr. 9. København 1907.

[2]) M. KNUDSEN. Danish Hydrographical investigations at the Færoe Islands in the spring of 1910. p. 7. Medd. fra Komm. for Havunders. Ser. Hydrogr. Bd. II, Nr. 1. København 1911.

[3]) FRIDTJOF NANSEN: The waters of the north-eastern North Atlantic, p. 24. Internat. Revue etc. 1913.

[4]) OVE PAULSEN: Plankton Investigations etc. Medd. fra Komm. for Havunders. Ser. Plankton. Bd. I, Nr. 8, p. 30. København 1909 and JOHS. SCHMIDT: The distribution of the pelagic fry etc. Conseil perm. internat., Rapp. et Proc. verb. Vol. 10, p. 221, Copenhague 1909.

It will be seen that the problem may also be formulated as follows: to find the distribution of a certain indicator for the water at the time t, the distribution at the time $t = 0$ being given; it is also evident that the solution will, *inter alia,* directly bear on the question of determining how the pelagic eggs on any spawning ground will be distributed throughout the adjacent water after the expiration of a certain time, provided that the eggs always have the same density as the surounding water.

In order to show what is required to solve this problem, I may advance the following considerations:

In a mass of water of infinite extent in all directions a certain indicator (salinity, temperature, colour etc.) is supposed to exhibit variation in one direction only, its intensity, however, being constant in planes perpendicular to such direction.

In order to develope certain expressions for the transposition of the water, I draw, through the point referred to, an abscissal axis X in the direction in which the variation takes place, with zero at this given point. I further suppose the distribution of the indicator to vary in course of time, by the movement of particles of water in the direction of the X axis, and by the interchange of water particles in such direction, presuming, however, that no distribution of water particles takes place perpendicularly to the direction of the X axis.

The entire mass of water is taken as being divided into discs by planes perpendicular to the X axis; the thickness of these we may call Δ_x. One of these discs, A_0 in Fig. 13, is to be so placed as to have its centre coinciding with zero on the abscissal axis.

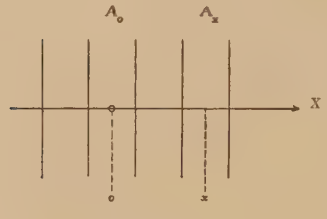


Fig. 13.

The amount of the indicator in 1 ccm in the lamella A with abscissa x at the time $t = 0$ we will call S, and the amount in A_0 being designated S_0.

After the lapse of 1 second, the distribution of S will be altered. In order to further investigate the relation of these changes to the movements which take place, I now proceed to consider a cylindrical body parallel with the X axis having a sectional area of 1 cm^2.

The movements within this body may be divided into two groups, the first group being characterised by the fact that the sum of the water quantities carried by them through the plane perpendicular to the X axis at the starting point is 0. It is for this group that I propose to formulate a summary expression, without regard to the nature of the movements in other respects.

The second group comprises that movement which is common to all particles in the direction of the abscissal axis. The velocity of this movement is equal to that volume of water which in the course of 1 second is passed through the section of the cylinder above referred to. This quantity of water I take as known, and then I suppose that a velocity equal and opposite to the translatory velocity found has been imparted to all the particles of water. It will then only remain to consider the movements of the first group.

The quantity of water from 1 ccm in the lamella A_x within the cylinder which is found in 1 ccm in the lamella A_0 after the lapse of 1 second I will then call q. We have then:

$$S_0 + \frac{dS_0}{dt} = \sum_{x=-\infty}^{x=+\infty} q \cdot S \cdot \Delta x. \tag{1}$$

At the time $t = 0$, we shall then have, with a certain approximation:

$$S = S_0 + \left(\frac{dS}{dx}\right)_0 \cdot x + \frac{1}{2} \cdot \left(\frac{d^2S}{dx^2}\right)_0 \cdot x^2. \tag{2}$$

In order to render (2) applicable to determination of S in (1), the variation of S and the corresponding q must be of such a nature that the error incurred by rejecting terms of higher order is insignificant. This

condition is complied with if the variation of q with x be such as to render q equal to 0 within that area where S can be expressed as in (2). Presuming this to be the case, we obtain:

$$S_0 + \frac{dS_0}{dt} = S_0 \cdot \sum_{x=-\infty}^{x=+\infty} q \cdot \Delta x + \left(\frac{dS}{dx}\right)_0 \sum_{x=-\infty}^{x=+\infty} q \cdot x \cdot \Delta x + \frac{1}{2}\left(\frac{d^2S}{dx^2}\right)_0 \sum_{x=-\infty}^{x=+\infty} q \cdot x^2 \cdot \Delta x.$$

Expressing this equation in integral terms, then since

$$\sum_{x=-\infty}^{x=+\infty} q \cdot \Delta x = 1. \tag{3}$$

We obtain

$$\frac{dS_0}{dt} = \left(\frac{dS}{dx}\right)_0 \cdot \int_{-\infty}^{+\infty} q \cdot x \cdot dx + \frac{1}{2} \cdot \left(\frac{d^2S}{dx^2}\right)_0 \cdot \int_{-\infty}^{+\infty} q \cdot x^2 \cdot dx. \tag{4}$$

The quantity q is a function of x, but since the nature of the movements in general is unknown, it cannot be exactly determined, and in order to carry the calculation further, with the object of obtaining an approximate expression for the transposition of the water, it will be necessary to choose for the function q an expression giving main features of the actual conditions.

I choose here the normal function of errors, multiplied by an expression of the first degree, such asymmetry as is thereby induced being as a rule necessary for indicating the movements of the water. I therefore set

$$q = k\,(1 + \beta x)\, e^{-\alpha^2 \cdot x^2}, \tag{5}$$

k indicating the value imparted to q at the starting point. In equation (5) k is, like α and β, a constant belonging to the point considered (the starting point); if, however, analogous expression be employed for another point with abscissa x, then other values for k and α will be obtained.

With the aid of (5), equation (4) may be stated thus:

$$\frac{dS_0}{dt} = \frac{k}{2\alpha^3} \cdot \sqrt{\pi} \cdot \left(\beta \cdot \left(\frac{dS}{dx}\right)_0 + \frac{1}{2}\left(\frac{d^2S}{dx^2}\right)_0\right) \tag{6}$$

while for determination of the constants included in this, we have the equation (3), which may now be stated:

$$k \int_{-\infty}^{+\infty} (1 + \beta x)\, e^{-\alpha^2 x^2} \cdot dx = 1$$

which gives

$$\alpha = \sqrt{\pi} \cdot k. \tag{7}$$

It is presumed that for a point with abscissa x, an equation analogous to (5) refering to the starting point can be formulated, and if the constant β in (5) were 0, it would then be possible to express the movement in question of the water in relation to the point x by an equation identical with (5). For in such case, the equation (5) would indicate that the movements of the water were symmetrical with regard to the arbitrarily chosen starting point, which presupposes them to be uniform at all points, and expressible by the same equation.

The constant β on the other hand, indicates that such uniformity does not exist, and that the movements vary in a definite way; from point to point the magnitude of this variation is taken, within the area considered, as proportional to x.

Even granting, however, that the movement varies by x, it is presumed, in the first place, that it can still be expressed by an equation in the form of (5), save only that k, and therefore α, must be supposed to be a function of x, and especially, within certain limits, a linear function of x, and in the second place that the quantity of water passing through the plane perpendicular to the X axis through the starting point be constantly = 0, as originally stipulated.

This given, it is possible to find the constant β expressed by k, and its variation with x.

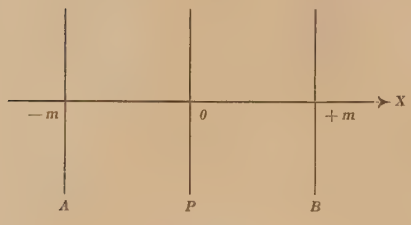


Fig. 14.

I therefore take:

$$k = k_0 (1 + rx); \tag{8}$$

k_0 being the value of k at the starting point, and r a constant. I take two planes, A and B; situate one on either side of the plane P through the starting point, at a distance m from this.

I now proceed to formulate an expression for the quantity of water carried during 1 second to 1 ccm situate in the plane A from places on that side of the plane P which is opposite to A; this quantity of water being called Q_A; and similarly, to formulate an entirely analogous expression for that quantity of water Q_B which in the course of 1 second, is carried to 1 ccm in the plane B from places on that side of the plane P which is opposite to B.

With the situation shown in Fig. 14, we can obtain, by means of (5) and (7)

$$Q_A = k_{-m} \int_0^\infty e^{-\pi k_{-m}^2 (x+m)^2} \cdot dx + \beta k_{-m} \int_0^\infty (x + m)\, e^{-\pi k_{-m}^2 (x+m)^2} \cdot dx = \frac{1}{\sqrt{\pi}} \int_{\sqrt{\pi} \cdot k_{-m} \cdot m}^\infty e^{-y^2} \cdot dy + \frac{\beta}{2\pi k_{-m}} \cdot e^{-\pi k_{-m}^2 m^2}$$

and the analogous equation:

$$Q_B = \frac{1}{\sqrt{\pi}} \int_{\sqrt{\pi} k_m m}^\infty e^{-y^2} \cdot dy - \frac{\beta}{2\pi k_m} \cdot e^{-\pi k_m^2 m^2}.$$

Hence we obtain, by means of (8), neglecting quantities of higher order

$$Q_A - Q_B = 2\pi k_0 r m^2 e^{-\pi k_0^2 m^2} + \frac{\beta}{\pi k_0} \cdot e^{-\pi k_0^2 m^2}.$$

When now the quantity of water carried by the movements through the plane P is = 0, we obtain:

$$\int_0^\infty (Q_A - Q_B)\, dm = 0$$

and by inserting the above expression here,

$$\frac{2r}{\pi \sqrt{\pi} k_0^2} - \int_0^\infty y^2 e^{-y^2} \cdot dy + \frac{\beta}{2\pi k_0^2} = 0$$

of which:

$$r = -\beta.$$

As, however, (8) gives

$$\frac{dk}{dx} = k_0 \cdot r$$

we have thus:

$$\frac{1}{k_0} \cdot \frac{dk}{dx} = -\beta. \tag{9}$$

By inserting this together with (7) in (6), we obtain, with S and k and their differential coefficients applying to the starting point:

$$\frac{dS}{dt} = \frac{1}{4\pi k^2}\left(-\frac{2}{k}\cdot\frac{dk}{dx}\cdot\frac{dS}{dx} + \frac{d^2S}{dx^2}\right)$$

As will be seen, this may be written:

$$\frac{dS}{dt} = \frac{d\,\frac{1}{4\pi k^2}\cdot\frac{dS}{dx}}{dx} \tag{10}$$

and writing this equation as

$$\frac{dS}{dt} = \frac{d\mu\frac{dS}{dx}}{dx} \tag{11}$$

we find

$$\mu = \frac{1}{4\pi k^2} \tag{12}$$

and

$$k = \frac{1}{\sqrt{4\pi\mu}} \tag{13}$$

It is thus evident, that if the quantity μ can by any means be determined, it is also possible to determine k, which done, an expression has been found for that amount of water which remains in the unit of volume after the lapse of one second.

By means of the formula (5) together with (7) and (9) we are further enabled to find an expression for the quantity of water found, after the expiration of 1 second, in 1 ccm at a point with co-ordinate x, originating from water which at the commencement of the second was situated at the starting point. This will be:

$$q_x = k_0\left(1 - \frac{1}{k_0}\left(\frac{dk}{dx}\right)_0\cdot x\right)e^{-\pi\,.\,k_0^2\,.\,x^2} \tag{14}$$

the indices for q, k, and $\frac{dk}{dx}$ denoting the abscissæ.

Naturally, we might, in the foregoing, have employed another unit of time throughout, e. g. t seconds. Taking the time measured in this unit as T and those analogous to the quantities μ, k, and q_x respectively as M, p, and $q_{x,t}$, it will then be seen from equation (11) that

$$M = t\cdot\mu.$$

As a consequence of this, and of (13)

$$p = \frac{1}{\sqrt{4\pi\cdot\mu t}}\cdot \tag{15}$$

If we further take

$$\varphi = p\cdot e^{-\pi p^2 x^2} \tag{16}$$

then the expression analogous with (14) for $q_{x,t}$ can be formulated thus:

$$q_{x,t} = \left(1 - \frac{p_x - p_0}{p_0}\right)\cdot\varphi. \tag{17}$$

0 and x indicating abscissæ and t the time. The formulæ (11), (15), (16) and (17) which have been derived for numerical calculation hold good for any unit of length and time, provided only that the same

unit be employed throughout. From the foregoing, $q_{x,t}$, is an abstract figure expressing a fraction of a cubic centimetre, but can naturally, independently of the other units, express the same fraction of any given unit of volume.

For the φ, a table is given below, with double entrance for the two arguments p and x.

Table 11.

p / x	0.01	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
0	0.0100	0.1000	0.2000	0.3000	0.4000	0.5000	0.6000	0.7000	0.8000	0.9000
1	0.0100	0.0969	0.1764	0.2261	0.2419	0.2280	0.1936	0.1501	0.1072	0.0707
2	0.0100	0.0882	0.1209	0.0968	0.0536	0.0215	0.0065	0.0015	0.0002	
3	0.0100	0.0754	0.0645	0.0236	0.0043	0.0005				
4	0.0100	0.0605	0.0268	0.0032	0.0001					
5	0.0099	0.0456	0.0086	0.0002						
6	0.0099	0.0323	0.0022							
7	0.0098	0.0214	0.0004							
8	0.0098	0.0134	0.0001							
9	0.0097	0.0078								
10	0.0097	0.0043								
11	0.0096	0.0022								
12	0.0096	0.0011								
13	0.0095	0.0005								
14	0.0094	0.0002								
15	0.0093	0.0001								

By means of equation (11), it is possible in certain concrete instances to determine the quantity μ. The equation is analogous to the Fourier equation for conduction of heat, save only that μ must here be considered as variable. GEHRKE[1]) has, in a detailed discussion of the dependence of the vertical temperature gradient upon mixing between water layers, employed the quantity μ to characterise the intensity of the mixing, and, in conformity with equation (11), defined μ as the quantity of heat carried by the mixings in the course of a unit of time through a certain unit of superficial area, when the temperature gradient in a direction perpendicular thereto is 1.

In the development here followed, μ will be the quantity of S carried in one second through 1 cm² perpendicular to the X axis and in the direction of same, when S decreases by one unit per cm. If other units of length or time be employed instead of those here named, the unit for μ will be altered accordingly.

The quantity μ is here presumed to be a function of x: if μ be independent of x, we then obtain the following, analogous with the Fourier equation:

$$\frac{dS}{dt} = \mu \cdot \frac{d^2S}{dx^2}.$$

I now return to the consideration of the translatory movement referred to on p. 28 and the backward and forward movement of the water particles mentioned in the foregoing.

Taking the velocity of the translatory movement as u, the increment in S occasioned by *both* movements is found to be:

$$\frac{dS}{dt} = -u \cdot \frac{dS}{dx} + \frac{d\mu \frac{dS}{dx}}{dx}. \qquad (18)$$

[1]) JOHAN GEHRKE: Om vertikale Varmestrømme i Havet. København 1912.

If (18) be employed under conditions where the distribution of the indicator S may be considered as stationary, then $\frac{dS}{dt} = 0$, and we obtain:

$$d\mu \frac{\frac{dS}{dx}}{dx} = u \frac{dS}{dx} \tag{19}$$

or

$$\mu \frac{dS}{dx} = uS \tag{20}$$

as the integration constant is seen to be 0, since μ expresses the quantity of S passed through a unit of surface, when $\frac{dS}{dx} = 1$.

Presuming that the translatory velocity u is known, together with the destribution of the indicator S, we may by means of (20) find μ.

If finally the mixing movements take place in all directions, the translatory velocity and the distribution of 3 different indicators given, we may by means of (20) find the quantity μ for the directions normal to the surfaces in which the indicators are constant, when we for u take the components of the translatory velocity in these directions.

In that way it will be possible to solve the problem generally, if sufficient hydrographical material is available, but also in particular cases the method will be of good service, especially if material be collected and treated with this process in view. It would in my opinion be desirable to thus compile such expressions for the very variable vortex movements in the North Atlantic and in the North Sea as might then be employed for further quantitative treatment in hydrographical problems of various kinds. Even with certain specialisations of the question, however, the available material will hardly be sufficient for the purpose, and I will restrict myself to giving an instance from the mixing of water-masses in the Trangisvaag Fjord.

V. Mixing of the water in Trangisvaag Fjord.

In investigating the mixing of water in Trangisvaag Fjord, I have employed the variation of salinity, in conformity with what has been set forth in the foregoing.

From the sections in Figs. 2 and 3 it will be seen that the position of the isohaline surfaces was not, the same on both days, 29th May and 6th June; there were, however, certain main features in common, as already described.

The present investigation presupposes a mean condition taken as stationary, and in relation to this, the position of the 35.1 $^0/_{00}$ isohaline in the section for 6th June must doubtless be regarded as abnormal, presumably due to the fact that the weather for some days previously had been unusually calm. The fact that the position in the section for 29th May is more indicative of the actual conditions is confirmed when we consider the distribution of the salinity at Stat. 7 for 3rd June, as shown in the tables.

It would naturally be desirable to have a larger amount of material for demonstration of the normal distribution of salinity; failing this, however, I have in Fig. 15, based especially on Figs. 2 and 3, drawn a somewhat schematic illustration of the isohaline surfaces, which will, however, in all probability be very near the actual mean conditions for May—June.

The section is drawn to the same scale as Figs. 2 and 3. The isohaline surfaces exhibit the usual obliquity; it should be noted, however, that if the section were drawn in its true proportions, the deviation from the horizontal would be difficult to observe, and consequently, when speaking of transport of water in a direction perpendicular to the isohaline surfaces, this is practically the same as transport in a vertical direction. Further, when determining $\frac{dS}{dx}$ perpendicular to the isohaline surfaces, the distance Δx between surfaces with a difference in salinity ΔS is determined by the length of a line which at the place in question is perpendicular to both surfaces, and which will in the figure appear as a vertical line; Δx is then measured by the distance between the points in which this cuts the two isohaline surfaces.

As already mentioned, the essential part of the inflow of fresh water takes places at the innermost part of the fjord, through a single river, and from the calculations on p. 11 as to the quantity of water, this may be taken as 0.4 m^3/sec.

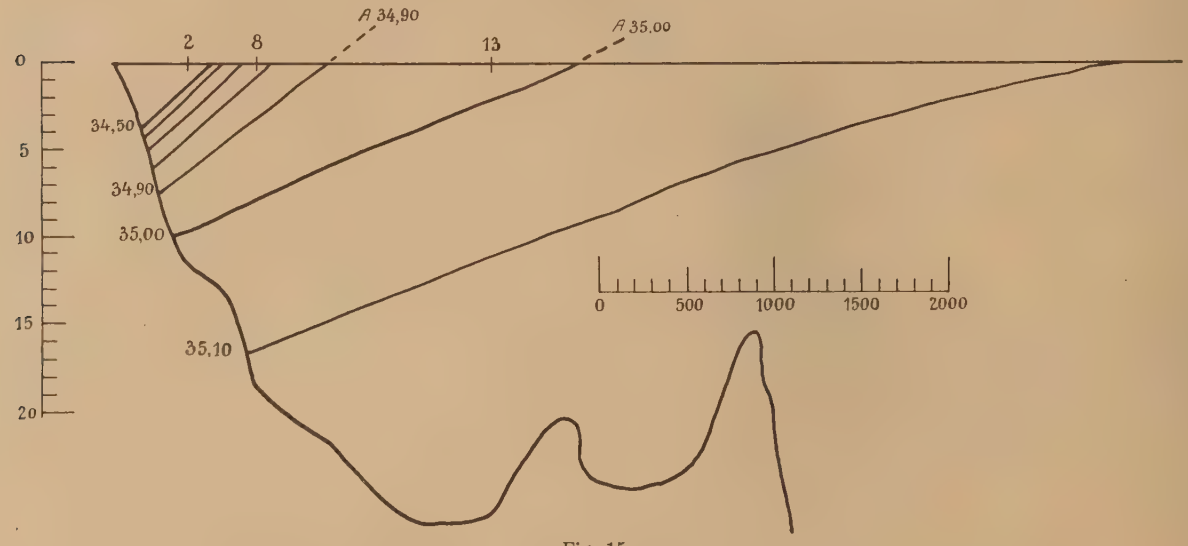


Fig. 15.

When this quantity of water enters the fjord, it becomes gradually mixed with the salt water, whence arises the distribution found.

The law of continuity now requires that just this amount of water shall be passed through the isohaline surfaces as a result of all the movements which occur. These may be highly variable, and of unknown character; we know, however, that existing differences of specific gravity necessitate that the mean value of the movement in the uppermost part of an isohaline surface shall be mainly outward as compared with the part nearest the bottom, and that the mean movement in this last is probably inward. According to Table 1, p. 11, we may presume that the difference in velocity in upper and under layer on account of difference in specific gravity, is in the highest about 2 cm/sec. at that part of the fjord, about midway between Stat. 2 and Stat. 8 in Fig. 15, where it may be supposed, from the position of the isohalines, to be greatest. Farther out in the fjord, as for instance at Stat. 13, the difference in specific gravity between upper and lower layer is considerably less, and the difference in velocity probably also far less.

The velocity of a water particle in a certain isohaline surface I will now consider as divided into two velocities, of which the one, u, is perpendicular to the surface in question, and constant for all particles in the same. The size of u should be such as to render $\int u \cdot dA =$ the quantity of water passed

through the isohaline surface in the course of a second: i. e. in the present instance, 0.4 m^3; dA indicates an element of area in the isohaline surface, and the integration should extend throughout the whole of the surface.

The components of the movements of the water particles which remain when the component u is subtracted will then be of such a nature that the quantity of water passed through the isohaline surface will, in mean value, be 0.

As the isohaline surfaces for the area to be considered in the following, viz: that about Stat. 13, are in reality very nearly horizontal, the component of velocity u will be very nearly vertical.

Further, if the mean value of the remaining velocity components for a portion of the isohaline surface have a value other than 0, then this must, in the uppermost portion of the isohaline surface, be presumed to be directed outwards, and inwards in that portion nearest the bottom. If these mean velocities are of the order of magnitude 0.5 cm/sec., then taking the difference in velocity as about 1 cm/sec. they will be nearly horizontal, since u is of the order of magnitude 10^{-4} cm/sec.

If the movement of the water is outwards in the upper layer and inwards in the bottom layer, then there must be a place between surface and bottom where the mean value of the velocities remaining after subtraction of the velocity u is 0. I will now formulate the equation for the mixing at this place, in the direction perpendicular to the isohaline surface.

Nothing is known as to the nature of the mixing movements, and they probably exist also in other directions than that perpendicular to the isohaline surface. Since, however, the distribution of salinity is to be used for determination of the magnitude of the mixing, only such movements as are perpendicular to the isohaline surface can be ascertained by this method.

If the axis be laid perpendicular to the isohaline surface considered, we then obtain by means of (20)

$$u A_S S = \mu A_S \frac{dS}{dx}$$

The value $u A_S$ is taken as $0{,}4 \frac{m^3}{sec} = 4 \cdot 10^5 \frac{cm^3}{sec}$ which gives

$$\mu = \frac{4 \cdot 10^5 \cdot S}{A_S \cdot \frac{dS}{dx}}$$

From the figure 15, and a chart, I will now employ the following approximate values in round figures for the quantities included in the formula:

$$A_{34.90} = 0.5 \cdot 10^{10} \text{ cm}^2 \qquad A_{35.00} = 1{,}4 \cdot 10^{10} \text{ cm}^2$$

$$\left(\frac{dS}{dx}\right)_{34.90} = 3{,}3 \cdot 10^{-4} \frac{‰}{cm} \qquad \left(\frac{dS}{dx}\right)_{35.00} = 1{,}3 \cdot 10^{-4} \frac{‰}{cm}$$

which gives

$$\mu_{34.90} = 8 \qquad \mu_{35.00} = 8.$$

The uncertainty of the values of μ however is very considerable; is must suffice to say that μ, at the place in question, is of the order of magnitude 10.

For the mixing coefficient I have on a previous occasion[1]) found far smaller values for the Great Belt; in the intermediate layer 0.05 and at the bottom 2. There is, however, also good reason to believe that the mixing in Trangisvaag Fjord is far stronger than in the Great Belt, especially since the difference between the densities in Trangisvaag is so slight.

Finally, Gehrke[2]) has, for the Bornholm Deep in the Baltic, found values which, with the units here employed, amount to the following:

Surface ..... $\mu = 13$
10 metres depth $\mu = 6$

As the surface water of the Baltic exhibits but slight differences in density, there would seem to be a very reasonable proportion between the values for the magnitude at the different places.

With a view to the practical application and use of Table 11, I prefer to reckon with the units metre and minute, and as μ according to (20) is determined by

$$\left[\frac{L^2}{T}\right]$$

then the value to be employed corresponding to $\mu = 8$ will be $\mu' = 0{,}05$ which according to (15) gives

$$p = \frac{1}{\sqrt{0{,}63 \cdot t}}$$

we have therefore, after the lapse of:

10	minutes	$p = 0{,}4$
18	—	$p = 0{,}3$
40	—	$p = 0{,}2$
159	—	$p = 0{,}1$
11	days	$p = 0{,}01$

Presupposing therefore, that the movements can be regarded in the manner described in the foregoing, we find from Table 11, for instance, that if an isohaline surface at the mentioned place in Trangisvaag Fjord contain a layer 1 metre thick with fish eggs uniformly distributed throughout in that layer, then after the lapse of ca. $2^1/_2$ hours, only $^1/_{10}$ of the original density will remain, whereas at a distance of 5 metres away, fish eggs will be found with a density equal to $^1/_{20}$ of that found in the original layer. Similarly, the density at 8—9 metres distance will at the expiration of that time be $^1/_{100}$ of the density in the original layer.

While matter thus suspended in a water layer will by mixing be carried to both sides of the layer, the total quantity of matter will be dislocated on account of the translatory velocity. In the present instance, this amounts to about 5 cm. per day perpendicularly to the isohaline surface at the place in question, and is thus extremely slight.

To this must be added the consideration that there exists in all probability an outward movement of the water in the upper layer and an inward in the lower. If the velocity be, as previously supposed, of the order of magnitude 0,5 cm/sec, this is equivalent to a movement of $^1/_2$ kilometre in the course of the 24 hours. Further investigation of the mixing would necessitate a closer acquaintance with this movement: it would moreover be necessary to take into consideration the changes in distribution of water particles from a certain layer arising from the limitation of the water region investigated.

[1]) J. P. Jacobsen: Beitrag zur Hydrographie der dänischen Gewässer. Medd. fra Kom. for Havunders. Bd. II. Nr. 2. S. 78. København 1913.

[2]) Johan Gehrke: Om vertikale Varmestrømme i Havet. S. 71. København 1912.

Synopsis.

The present paper consists, as regards its Section I, of a monograph on certain of the Færoe Fjords, especially Trangisvaag Fjord. Fig. 1 shows the position of the stations in Trangisvaag Fjord on the basis of which the distribution of temperature and salinity in certain sections has been shown in Figs. 2 and 3. The characteristic feature of this distribution is the oblique position of the isohaline surfaces, due to the inflow of fresh water into the inner portion of the fjord, and of salt water from the sea without. The interchange of fjord water with that of the sea must be presumed to take place with comparative rapidity. Some calculations as to the intensity of that interchange will be found in the concluding portion of the paper. The observation material available from the Færoe Fjords is shown in the tables appended. From these observations it appears that the conditions are very much the same in all fjords, the salinity in the deep outermost portion of all fjords being approximately the same — viz. about 35.17 $^0/_{00}$ — for all.

In addition to the description of the distribution of temperature and salinity as found, Section I further treats of the causes which determine the movement of the water in Trangisvaag, the relation between the water level in the fjord and the barometer level being at the same time subject to closer investigation. As regards this, it has been found that the water level of the fjord closely follows the alterations which take place in the barometer level (*vide* Fig. 8); this may be taken as generally applicable to the waters around the Færoes. In addition to the changes concurrent with those of the barometer, we also find (*vide* Fig. 9) a period of about 14 days in the changes of water level; the influence of the wind, on the other hand, upon the water level, has been found to be extremely slight.

Section II treats of the tidal movement on the Færoe Bank, about 60 nautical miles SW of Suderø. Current measurement made there on the 12. June 1913 — at the surface and at 50 metres depth — showed the tidal movement to be very strong (*vide* Figs. 10a and 10b). The current changed its direction all round the compass with approximately equal velocity, exhibiting a velocity of about 2 nautical miles per hour in the different directions at the different hours.

The observations also indicated a constant current of about $^1/_3$ nautical mile per hour.

Section III deals with the current in the Færoe-Shetland Channel and the mixing of water on the Banks, on the basis of all material from these regions published in the »Bulletin Hydrographique«.

It has been found — in accordance with NANSEN's previous investigations — that the north-going current along the Shetlands and the Scottish coast is strongest at those places where the depth to bottom is between 150 and 200 metres. The same has been found to be the case as regards the south-going current along the eastern side of the Færoe Plateau. The investigations have been carried out for each single months from May to November.

It has further proved possible, by means of the difference between the temperatures at 50 and 100 metres' depth, to characterize the mixing between the different layers of the sea on the banks and over greater depth. On the banks at the Færoe plateau itself and on the Færoe Bank about 60 nautical miles SW of Suderø, the mixing between the layers was found to be especially intense; this is in all probability partly due to the strong tidal currents. On the banks near the Shetlands and the Scottish coast also, we find a high degree of mixing between the layers, though by no means so intense as at the Færoes. At the deeper places in the Færoe Shetland Channel, the mixing is less pronounced. This difference in the mixing of the water over banks and in deeper places must presumably be the cause of the characteristic hydrographical conditions which several hydrographers have found to exist on banks.

Section IV contains a mathematical examination of the mixing between the layers, the object being to provide a means for determining the distribution of pelagic organisms from a certain spot to the waters adjacent. The problem can be solved when once constants have been found indicating the intensity of mixing in the water. By way of example, such a constant has, in Section V, been found for Transgisvaag; the value found appears to be of a reasonable size when compared with similar quantities obtained from other localities.

Observations as to temperature, salinity and amount of oxygen in certain fjords of the Faeroes*).

Trangisvaag Fjord.

Station 1.

Date	Time hour	Time min.	Time a. m. or p. m.	Depth m	Temp. °C	Salin. ‰	σ_t
1913							
June 3	2	00	p	0	8.0	34.69	27.04
				1	1	67	01
				2	1	81	13
				3	1	88	18
				5	0	97	28
» »	2	30	p	9.5	7.8	35.07	38
» 7	2	10	p	0		25.43	

Station 2.

Date	Time hour	Time min.	Time a. m. or p. m.	Depth m	Temp. °C	Salin. ‰	σ_t
1913							
May 29	10	00	a	0	9.0	26.81	20.75
				1	8.4	34.40	26.76
				2	2	67	27.00
				3	2	85	14
				5	1	85	16
				11	0	35.03	32
June 3	2	35	p	0	8.0	34.79	27.13
				1	0	83	16
				2	0	88	20
				3	0	88	20
				5	0	35.03	32
» »	2	55	p	11.5	0	08	36
June 5	8	30	p	0	8.9	34.67	26.89
				1	9	79	99
				2		35.05	—
				3	1	08	27.34
				5	0	10	38
» »	9	00	p	13	0	10	38
June 6	9	25	a	0	8.8	32.14	24.93
				1	5	34.58	26.89
				2	4	54	89
				3	4	92	27.18
				5	3	35.07	30
				10	7.7	10	43
				11	7	10	43
June 7	2	05	p	0		33.53	
June 7	8	45	p	0		24.74	
June 8	10	40	a	0		34.45	

Station 3.

Date	Time hour	Time min.	Time a. m. or p. m.	Depth m	Temp. °C	Salin. ‰	σ_t
1913							
June 3	4	15	p	0	8.0	34.96	27.26
				1	0	94	25
				2	0	94	25
				3	0	94	25
				5	0	94	25
				10	7.9	35.07	36
» »	4	35	p	13	9	10	39

(Station 3 continued).

Date	Time hour	Time min.	Time a. m. or p. m.	Depth m	Temp. °C	Salin. ‰	σ_t
1913							
June 6	11	35	a	0	9.3	32.21	24.91
				1	8.1	34.87	27.17
				2	7.9	35.07	36
				3	8	07	37
				5	7	10	42
				10	7	14	45
				13	7	16	47
June 7	2	18	p	0		29.14	

Station 4.

Date	Time hour	Time min.	Time a. m. or p. m.	Depth m	Temp. °C	Salin. ‰	σ_t
1913							
June 3	3	05	p	0	8.1	34.88	27.18
				1	1	96	24
				2	1	94	23
				3	1	94	23
				5	1	97	26
				10	0	35.07	35
» »	3	30	p	14.5	0	10	38
June 5	7	00	p	0	10.6	30.46	23.33
				1	9.1	34.88	27.03
				2	7.8	97	31
				3	8.3	35.03	27
				5	0	07	35
				10	0	10	38
» »	7	45	p	20	7.9	10	39
June 6	11	05	a	0	9.7	25.97	20.00
				1	8.8	34.40	26.70
				2	2	92	27.20
				3	2	35.01	28
				5	7.7	10	42
				10	7	10	42
				13	7	12	43
June 7	2	00	p	0		33.55	
June 7	2	40	p	0		33.31	
June 7	8	30	p	0		29.04	
June 8	10	35	a	0		34.56	
June 16	4	50	p	0	8.9	34.90	27.08
				1	8	90	09
				2	7	90	11
				3	6	35.03	22
				5	5	05	25
				10	2	12	36
» »	5	15	p	13	1	16	41

*) Observations and collection of samples from Vaag Fjord June 1910 by cand. polyt. S. Palitzsch.
— — — 1910—11 by Capt. Alf. Trolle.
— — — 1912 by Capt. G. Hansen.
— — — 1913 by J. P. Jacobsen.

The position of the stations for 1912 and 1913 will be seen from Fig. 1 and Fig. 4.
The determinations of salinity and oxygen content in the samples collected have been carried out by the Hydrographical Laboratorium, with the exception of the samples collected by S. Palitzsch.

Station 5.

Date	Time hour	Time min.	Time a. m. or p. m.	Depth m	Temp. °C	Salin. °/₀₀	σ_t
1913							
June 3	4	45	p	0	8.0	35.03	27.32
				1	0	03	32
				2	0	03	32
				3	0	03	32
				5	0	05	33
				10	7.9	08	37
»	5	00	p	13	9	10	39
June 6	10	35	a	0	8.7	34.60	26.87
				1	2	83	27.13
				2	2	90	19
				3	0	35 07	35
				5	7.8	10	41
				10	7	08	39
				14	7	10	42
June 7	2	20	p	0		32.74	

Station 6.

Date	Time hour	Time min.	Time a. m. or p. m.	Depth m	Temp. °C	Salin. °/₀₀	σ_t
1913							
May 29	11	20	a	0	8.6	34.70	26.97
				1	5	52	84
				3	4	65	95
				5	0	35.01	27.32
				14	7.8	07	38

Station 7.

Date	Time hour	Time min.	Time a. m. or p. m.	Depth m	Temp. °C	Salin. °/₀₀	σ_t
1913							
June 3	3	35	p	0	8.0	34.97	27.28
				1	0	99	29
				2	0	99	29
				3	0	99	29
				5	0	99	29
				10	0	35.05	33
»	3	55	p	17	7.9	10	39
June 5	9	30	p	0	9.2	30.07	23.25
				1	8.8	34.78	27.00
				2	2	35.07	32
				3	1	05	31
				5	0	08	36
				10	0	08	36
» »	10	00	p	16	7.9	08	37
June 6	11	58	a	0	8.8	34.61	26.88
				1	0	35.03	27.31
				2	7.8	14	44
				3	8	14	44
				5	7	14	45
				10	7	16	46
				17	6	16	48
June 7	1	40	p	0		33.62	
June 7	8	30	p	0		31.35	
June 8	10	35	a	0		34.56	

Station 8.

Date	Time hour	Time min.	Time a. m. or p. m.	Depth m	Temp. °C	Salin. °/₀₀	σ_t
1913							
May 29	10	50	a	0	8.5	34.92	27.16
				1	2	90	19
				3	2	97	26
				5	1	35.01	29
				14	7.8	10	41

Station 9.

Date	Time hour	Time min.	Time a. m. or p. m.	Depth m	Temp. °C	Salin. °/₀₀	σ_t
1913							
May 29	10	30	a	0	8.5	34.90	27.15
				1	3	94	20
				3	1	99	27
				5	2	99	27
				11	7.9	35.05	35

Station 10.

Date	Time hour	Time min.	Time a. m. or p. m.	Depth m	Temp. °C	Salin. °/₀₀	σ_t
1913							
May 29	1	00	p	0	8.5	35.03	27.25
				2	3	34.99	25
				5	2	99	26
				10	7.9	35.01	32
» »	1	10	p	14	7	07	40
June 6	2	25	p	0	8.7	35.01	27.20
				1	2	07	32
				2	1	07	34
				3	0	10	39
				5	7.8	16	45
				10	7	16	46
» »	2	45	p	21	7	16	46
June 16	5	50	p	0	8.6	35.03	27.23
				1	6	05	24
				2	6	05	24
				3	5	07	28
				5	4	05	26
				10	1	16	40
» »	6	10	p	21	7.9	14	42

Station 11.

Date	Time hour	Time min.	Time a. m. or p. m.	Depth m	Temp. °C	Salin. °/₀₀	σ_t
1913							
June 5	4	00	p	0	9.2	33.66	26.06
				2	8.0	35.03	27.32
				5	7.8	10	41
				10	7	08	40
				20	7	10	42
June 5	5	00	p	0	10.3	31.44	24.15
				2	7.9	35.05	27.34
				20	7	10	42
June 5	6	00	p	0	9.6	33.31	25.72
				2	8.6	34.78	27.03
				20	7.7	35.10	42
June 5	7	00	p	0	9.3	34.04	26.33
				2	8.5	85	27.09
				5	7.8	35.08	39
				10	7	10	42
				20	7	10	42
June 5	8	00	p	0	9.0	34.36	26.64
				2	7.7	35.10	27.42
				19	7	10	42
June 5	9	00	p	0	9.0	34.45	26.70
				2	8.1	54	92
				18	7.8	35.10	27.41
June 5	10	00	p	0	7.9	34.54	26.95
				2	9	35.05	27.34
				5	8	07	38
				10	8	10	41
				19	0	10	52
June 5	11	00	p	0	8.0	32.63	25.44
				2	0	35.03	27.32
				19	7.6	08	42

(Station 11 continued).

Date	Time hour	Time min.	Time a. m. or p. m.	Depth m	Temp. °C	Salin. ‰	σ_t
1913							
June 5	12	00	p	0	9.1	33.28	25.77
				2	8.2	35.03	27.29
				19	2	10	36
June 6	1	00	a	0	8.9	35·10	27.24
				2	7.9	05	34
				5	8	08	39
				10	7	10	42
				20	7	10	42
June 6	2	00	a	0	9.0	33.60	26.05
				2	7.9	35.07	27.36
				20	7	16	46
June 6	3	00	a	0	8.8	34.00	26 39
				2	1	35.05	27.31
				20	7.7	16	46
June 6	4	00	a	0	8.6	34.61	26.90
				2	7.8	35.07	27.38
				5	7	08	40
				10	7	08	40
				19	7	12	43
June 6	5	00	a	0	8.7	33.15	25.75
				2	7.8	35.08	27.40
				20	7	12	43
June 6	6	00	a	0	8.3	34.99	27.24
				2	7.8	35.10	41
				20	7	10	42
June 6	7	00	a	0	9.1	33.78	26.17
				2	7.8	35.10	27.41
				5	7	10	42
				10	8	12	42
				20	7	14	45
June 6	8	00	a	0	8.7	34.43	26.74
				2	7.8	35.07	27.38
				20	7	14	45

Station 12.

1913							
May 19	2	00	p	0	7.3	35.16	27.52
				5	2	12	49
				10	2	12	50
				20	2	10	49
» »	2	20	p	26	2	12	50
May 19	7	20	p	0	7.2	35.16	27.53
				5	2	12	50
				10	2	14	52
				20	2	14	52
» »	7	50	p	26	2	14	52
May 20	7	30	a	0	7.2	35.16	27.53
				5	1	12	52
				10	1	10	50
				20	1	12	52
» »	7	50	a	26	1	14	54
May 20	1	25	p	0	7.3	35.16	27.51
				5	2	14	52
				10	2	16	54
				20	1	17	56
» »	1	50	p	26	1	17	56
June 1	11	30	a	0	8.2	34.76	27.07
				20	7.6	35.07	41
June 1	0	30	p	0	8.5	34.63	26.93
				20	7.7	99	27.33

(Station 12 continued).

Date	Time hour	Time min.	Time a. m. or p. m.	Depth m	Temp. °C	Salin. ‰	σ_t
1913							
June 1	1	30	p	0	8.6	34.61	26.90
				20	7.7	35.01	27.35
June 1	2	30	p	0	8.8	34.74	26.97
				13	7.7	97	27.32
June 1	3	30	p	0	8.7	34.72	26·96
				14	7.6	35.07	27·41
June 1	4	30	p	0	8.6	34.72	26.98
				14	7.7	35.05	27.37
June 1	5	30	p	0	8.7	34.38	26.71
				14	7.6	35.08	27.42
June 1	6	30	p	0	8.6	33.98	26.41
				14	7.6	35.01	27.37
June 1	7	30	p	0	8.6	34.16	26.54
				13	7.6	35.12	27.45
June 1	8	30	p	0	8.4	34.45	26.80
				13	7.6	35.05	27.39
June 1	9	30	p	0	8.4	34.11	26.54
				13	7.6	35.08	27.42
June 2	6	30	a	0	—	34.69	—
				19	7.6	35.14	27.47
June 2	7	30	a	0	8.2	34.63	26.98
				20	7.7	35.10	27.42
June 2	8	30	a	0	8.2	34.79	27.10
				20	7.6	35 08	42
June 2	9	30	a	0	8.2	34.85	27·14
				20	7.6	35.12	45
June 2	11	30	a	0	8.1	34.97	27.26
				20	7.6	35.12	45
June 2	7	15	p	0	8.0	34.87	27·19
				20	7.8	35.05	36
June 2	8	00	p	0	8.0	34.87	27.19
				20	7.8	35.03	35
June 2	9	00	p	0	8.0	34·76	27·10
				20	7.7	35 05	37
June 2	10	00	p	0	8.0	34.92	27.23
				20	7.7	—	—
June 2	11	00	p	0	8.0	34.92	27.23
				20	7.9	35.05	34
June 2	12	00	p	0	8.0	34.83	27.16
				14	7.9	99	30
June 3	1	00	a	0	8.2	34.25	26.67
				14	7.8	99	27.32
June 3	2	00	a	0	7.8	34.27	26.75
				15	8	97	27.31
June 3	3	00	a	0	8.2	33.42	26.03
				14	7.8	35.05	27.36
June 3	4	00	a	0	8.4	31·71	24 65
				14	7.9	35.05	27.34
June 3	5	00	a	0	8.4	31.82	24.74
				15	7.8	35.07	27.38
June 3	6	00	a	0	8.4	29.70	23.08
				17	7.8	35.07	27.38
June 3	7	00	a	0	8.5	29.27	22.74
				16	7.8	35.05	27.36
June 3	8	00	a	0	8.6	30.21	23.46
				20	7.7	35.08	27.40

(Station 12 continued).

Date	Time hour	Time min.	Time a. m. or p. m.	Depth m	Temp. °C	Salin. ‰	σ_t
1913							
June 3	9	00	a	0	8.7	28.66	22.23
				20	7.7	35.10	27.42
June 3	10	00	a	0	8.8	26.08	20.21
				20	7.7	35.14	27.45
June 3	11	15	a	0	8.6	31.82	24.71
				2	2	33.04	25.73
				5	7.8	34.99	27.32
				10	7	35.08	40
				15	7	08	40
June 3	3	00	p	0	8.1	34.88	27.18
				2	0	87	19
				20	7.7	35.10	42
June 3	4	00	p	0	8.1	34.88	27.18
				2	7.9	90	23
				5	9	88	21
				10	8	97	31
				20	7	35.10	42
June 3	5	00	p	0	8.1	34.88	27.18
				2	7.9	88	21
				20	6	—	—
June 3	6	00	p	0	8.0	34.92	27.23
				2	7.9	97	29
				20	6	35.14	47
June 3	7	00	p	0	8.0	34.96	27.26
				2	7.8	97	31
				5	8	97	31
				10	8	35.03	35
				20	7	17	48
June 3	8	00	p	0	8.0	35.03	27.32
				2	7.8	01	34
				20	6	17	49
June 3	9	00	p	0	8.0	35.01	27.31
				2	7.8	01	34
				20	7	17	48
June 3	10	00	p	0	8.0	35.01	27.31
				2	7.8	01	34
				5	8	01	34
				10	8	10	41
				20	7	16	46
June 3	11	00	p	0	8.0	34.85	27.17
				2	7.9	92	24
				20	7	35.16	46
June 3	12	00	p	0	7.9	34.92	27.24
				2	8	92	26
				20	7	35.16	46
June 4	1	00	a	0	7.8	34.96	27.29
				2	8	97	31
				5	9	35.03	33
				10	8	03	35
				20	7	16	46
June 4	2	00	a	0	7.9	34.92	27.24
				2	8	92	26
				20	6	35.16	48
June 4	3	00	a	0	7.9	34.72	27.08
				2	7	72	11
				20	7	35.16	46
June 4	4	00	a	0	8.0	34.65	27.02
				2	7.8	99	32
				5	8	35.01	34
				10	7	10	42
				20	7	16	46

(Station 12 continued).

Date	Time hour	Time min.	Time a. m. or p. m.	Depth m	Temp. °C	Salin. ‰	σ_t
1913							
June 4	5	00	a	0	8.0	34.47	26.88
				2	7.8	99	27.32
				20	7	35.10	42
June 4	6	00	a	0	8.0	34.79	27.13
				2	7.8	—	—
				20	7	35.12	27.43
June 4	7	00	a	0	8.0	34.78	27.12
				2	7.8	35.03	35
				5	8	10	41
				10	7	16	46
				20	7	16	46
June 4	8	00	a	0	8.0	34.99	27.29
				2	7.8	35.03	35
				20	7	16	46
June 4	9	00	a	0	8.2	34.85	27.14
				2	7.9	85	18
				20	7	35.16	46
June 5	2	00	p	0	8.7	33.89	26.32
				2	7.9	35.03	27.33
				5	9	03	33
				10	7	10	42
				20	7	10	42

Station 13.

1913							
May 29	3	10	p	0	8.7	34.99	27.19
				2	4	99	22
				5	4	35.05	27
				10	7.9	08	37
				20	7	16	47
» »	3	40	p	26	5	19	52
June 6	3	00	p	0	8.9	34.92	27.10
				1	5	35.01	23
				2	4	01	25
				3	7.9	12	40
				5	7	16	46
				10	7	16	46
» »	3	25	p	24	7	14	45

Station 14.

1913							
May 29	5	00	p	0	9.3	33.80	26.15
				2	8.8	34.52	79
				5	0	35.05	27.33
				10	7.7	14	46
» »	5	10	p	20	7	16	47
June 6	4	05	p	0	8.8	34.88	27.08
				1	6	92	14
				2	0	35.10	38
				3	7.9	12	41
				5	7	16	46
				10	7	16	46
» »	4	30	p	23	7	16	46
June 16	8	00	p	0	8.8	34.94	27.13
				1	6	35.01	21
				2	5	08	29
				3	4	12	33
				5	4	10	32
				10	1	16	40
				20	0	16	42
» »	8	15	p	27	7.9	16	43

Station 15.

Date	Time hour.	Time min.	Time a. m. or p. m.	Depth m	Temp. °C	Salin. °/₀₀	σ_t
1913							
May 29	4	20	p	0	8.8	34.99	27.16
				2	2	35.12	37
				5	1	16	41
				10	7.8	17	47
» »	4	30	p	17	5	17	50
June 6	3	30	p	0	8.7	35.14	27.31
				1	4	34.96	19
				2	1	35.07	33
				3	1	10	37
				5	7.8	16	45
				10	7	14	45
» »	3	50	p	19	7	16	46

Station 16.

Date	Time hour.	Time min.	Time a. m. or p. m.	Depth m	Temp. °C	Salin. °/₀₀	σ_t
1913							
May 29	5	25	p	0	8.2	35.01	27.29
				2	0	01	32
				5	0	01	32
				10	7.7	14	45
» »	5	35	p	23	5	19	52
June 6	6	15	p	0	8.8	34.92	27.11
				1	8	35.05	21
				2	6	34.96	17
				3	2	35.03	29
				5	0	03	32
				10	7.7	14	45
» »	6	35	p	25	7	16	46

Station 17.

Date	Time hour.	Time min.	Time a. m. or p. m.	Depth m	Temp. °C	Salin. °/₀₀	σ_t
1913							
May 29	5	50	p	0	8.6	34.67	26.95
				2	2	78	27.09
				5	7.8	35.16	47
				10	6	19	52
				20	6	17	51
				30	5	19	52
» »	6	15	p	31	5	—	—
May 31	9	40	a	0	8.5	33.48	26.02
				2	2	34.42	80
				5	7.9	90	27.24
				10	6	35.14	47
				20	6	16	48
» »	10	10	a	30	6	14	47
June 6	6	50	p	0	8.8	34.81	27.03
				1	2	35.03	29
				2	2	10	35
				3	5	34.83	09
				5	2	35.03	29
				10	7.7	16	46
				20	7	16	46
» »	7	15	p	31	7	16	46
June 16	9	50	a	0	8.2	35.17	27.40
				5	1	16	40
				10	1	17	42
				20	1	17	42
				30	1	19	43
» »	10	05	a	34	0	19	45
June 16	10	20	p	0	8.4	35.12	27.33
				5	2	12	36
				10	1	16	40
				20	1	17	42
» »	10	30	p	30	0	16	42

Station 18.

Date	Time hour.	Time min.	Time a. m. or p. m.	Depth m	Temp. °C	Salin. °/₀₀	σ_t
1913							
May 30	7	25	a	0	7.8	35.17	27.46
				5	5	16	49
				10	5	16	49
				20	5	14	48
				30	5	16	49
				42	5	16	49
June 6	9	20	p	0	8.1	35.14	27.39
				1	7.9	14	42
				5	8	14	44
				10	8	14	44
				20	7	14	46
				30	7	14	46
				56	7	14	46
June 16	11	10	p	0	8.0	35.17	27.43
				5	0	16	41
				10	0	16	41
				20	0	16	41
				30	0	16	41
» »	11	25	p	44	0	16	41

Vaag Fjord.

Station 1.

Date	Time hour.	Time min.	Time a. m. or p. m.	Depth m	Temp. °C	Salin. °/₀₀	σ_t
1913							
June 17	1	30	p	0	9.1	33.31	25.81
				1	8.9	37	87
				2	7	34.54	26.84
				3	6	72	99
	1	15	p	5	6	83	27.07
June 18	4	00	p	0	9.4	32 90	25.43
				1	3	33.48	91
				2	1	34.18	26.48
				3	8.9	70	93
	3	40	p	5	8	70	94
June 19	1	50	p	0	10.0	31.65	24.36
				1	9.6	33.69	26.02
				2	6	75	07
				3	5	34.14	39
	1	35	p	4.5	0	65	87
June 20	1	50	p	0	11.0	33.15	25.36
				1	10.2	34.00	26.16
				2	9.6	54	68
				3	5	70	83
	1	35	p	5	2	83	97

Station 2.

Date	Time hour.	Time min.	Time a. m. or p. m.	Depth m	Temp. °C	Salin. °/₀₀	σ_t
1912							
May 15	6	48	p	0	9.1	34.38	26.64
				5	7.8	35.08	27.39
				10	5	16	49
	6	35	p	19	4	16	50
May 24	7	15	p	0	8.3	35.16	27.38
				5	7.9	16	43
				10	8	16	46
	7	05	p	20	6	16	48
May 25	6	20	a	0	7.7	35.16	27.46
				5	6	16	47
				10	6	17	50
	6	10	a	19	6	17	50

(Station 2 continued).

Date	Time hour.	Time min.	Time a. m. or p. m.	Depth m	Temp. °C	Salin. °/₀₀	σ_t
1913							
June 20	3	00	p	0	9.4	35.07	27.12
				2	4	07	13
				5	9.3	07	14
				10	3	14	20
				15	8.6	16	32
	2	40	p	18	1	16	40

Station 3.

1912							
May 16	5	15	p	0	8.2	35.08	27.33
				5	7.6	10	43
				10	4	16	50
	5	00	p	20	4	23	55
May 24	5	35	p	0	8.1	35.17	27.42
				5	7.8	17	45
				10	7	16	46
	5	20	p	19	6	17	49
May 25	7	50	a	0	7.9	35.17	27.44
				5	8	17	46
				10	8	17	47
	7	35	a	18	7	17	48

Station 4.

1912							
May 16	5	50	p	0	7.8	35.16	27.45
				5	8	14	44
				10	6	12	45
				20	4	14	49
				30	4	16	51
				40	4	16	51
	5	25	p	45	4	16	51
May 24	6	10	p	0	8.3	35.17	27.39
				5	2	16	39
				10	0	16	41
				20	7.7	16	45
				30	6	17	49
				40	6	17	50
	5	45	p	44	5	16	49
May 25	7	25	a	0	8.0	35.16	27.41
				5	7.8	17	46
				10	8	17	47
				20	7	17	48
				30	7	17	48
	7	10	a	43	6	17	49
1913							
June 20	4	00	p	0	9.4	35.14	27.18
				5	0	14	26
				10	8.4	16	36
				20	2		
				30	1	17	42
	3	50	p	47	0	17	42

Station 5.

1912							
May 16	6	10	p	0	7.8	35.16	27.45
				5	7	10	42
				10	5	14	48
	6	00	p	18	4	16	50

(Station 5 continued).

Date	Time hour.	Time min.	Time a .m. or p. m.	Depth m	Temp. °C	Salin. °/₀₀	σ_t
1912							
May 24	6	35	p	0	8.8	35.12	27.26
				5	6	14	31
				10	4	14	34
				14	2	12	36
	6	20	p	17	7.7	16	47
May 25	6	55	a	0	8.6	35.16	27.33
				5	4	14	35
	7	00	a	6	2	17	38
				7	7.9		
				8	8		
				10	8	35.16	27.44
	6	45	a	19	6	16	47

Station 6.

1912							
May 15	4	40	p	0	7.8	35.10	27.41
				5	6	10	43
				10	6	14	47
				20	6	14	47
				30	5	14	48
				40	4	16	50
				50	4	16	50
				60	4	19	53
	4	00	p	63	4	16	50
May 24	4	55	p	0	8.0	35.17	27.43
				5	7.9	17	46
				10	8	16	44
				20	7	17	48
				30	6	16	47
				40	6	17	49
				50	6	17	49
				60	6	16	47
	4	10	p	68	6	16	48
May 25	9	10	a	0	7.9	35.17	27.44
				10	8	17	47
				20	7	16	46
				30	7	17	48
				40	7	17	48
				50	6	17	48
				60	6	17	48
	8	35	a	69	6	17	49
1913							
June 20	5	15	p	0	9.5	35.16	27.18
				5	0	16	28
				10	8.3	16	37
				20	1	17	42
				40	1	17	43
	5	00	p	62	0	16	42

Vaag Fjord.

(No statement of the position in the fjord).

1910							
June 1				0	8.4	34.72	27.01
				12	7.4	35.00	38
				23	2	07	46

Sands Vaag.

1912							
June 22	7	00	p	0	9.2	34.92	27.04
				5	8.7	35.10	26
				10	6	17	34

Nolsø Fjord.

Date	Time hour.	Time min.	Time a. m. or p. m.	Depth m	Temp. °C	Salin. ‰	σ_t
1910							
October 19	8	00	a	1/2	9.2	35.14	27.22
	8	30	a	25	2	10	19
	8	20	a	50	2	14	22
	8	10	a	73	2	10	19
October 26	6	30	a	1/2	9.2		
	6	25	a	25	1		
	6	20	a	50	1		
	6	15	a	75	1		
November 5	10	40	a	1/2	8.6	35.14	27.32
	11	10	a	25	6	14	32
	11	00	a	50	6	14	32
	10	50	a	75	6	12	30
November 21	9	50	a	1/2	7.3	35 16	27.52
	9	40	a	25	2	17	55
	9	35	a	50	2	17	55
	9	30	a	75	2	25	60
November 28	10	10	a	1/2	6.9		
				25	7.0		
				50	0		
	9	50	a	75	0		
December 19	9	45	a	1/2	6.8	35.10	27.55
				25	8		
				50	8	35.14	27.58
	9	25	a	75	8	10	55
December 27	10	00	a	1/2	6.4		
	10	10	a	75	4		
1911							
January 10	9	50	a	1/2	5.8	35.03	27.62
				25	8	35.03	62
				50	8	35.01	61
	9	30	a	75	8	35.03	62
January 26	9	50	a	1/2	5.6	34.88	27.53
				25	6	88	53
				50	6	94	58
	9	30	a	75	6	94	58
February 15	10	55	a	1/2	5.9	35.07	27.64
				50	9	05	62
	10	40	a	75	9	10	67
February 27	8	45	a	1/2	5.6	35.08	27.69
				50	4	19	80
	8	35	a	75	4	07	70
March 18	7	45	a	1/2	5.4	35.19	27.80
				50	4	14	76
	7	35	a	75	5	14	75
March 27	8	45	a	1/2	5.6	35.08	27.69
				25	6		
				50	6	35.12	27.72
	8	30	a	75	7	14	73
April 11	8	45	a	1/2	6.0	35.19	27.73
				25	0		
				50	0		
	8	30	a	75	0	35.19	27.73
April 27	1	15	p	1/2	6.2		
				50	2		
	1	25	p	75	2	35.12	27.64
May 15	1	45	p	1/2	6.7	35.14	27.59
	1	35	p	50	7	16	60
	1	40	p	75	7	16	60

(Nolsø Fjord continued).

Date	Time hour.	Time min.	Time a. m. or p. m.	Depth m	Temp. °C	Salin. ‰	σ_t
1912							
June 27	6	00	p	0	8.6	35.17	27.34
				10	5	19	36
				20	5	17	35
				30	5	17	35
				40	5	17	36
				50	5	17	36
				75	5	17	36
				87	5	16	34

Vestmannasund off Vestmanhavn.

1910							
October 20	11	30	a	1/2	9.2	35.16	27.23
	11	55	a	23	2	12	20
	11	35	a	40	2	12	20
November 4	8	10	a	1/2	8.7		
	8	30	a	25	7		
	8	20	a	50	7		
November 26	10	30	a	1/2	7.2	35.12	27.50
				25	2	12	50
	10	10	a	50	2	12	50
December 5	12	15	p	1/2			
	12	20	p	25			
	12	10	p	50			
December 15	9	30	a	1/2	7.0	35.07	27.49
				25	0	08	50
	9	10	a	50	0	10	52
December 30	9	25	a	1/2	6.4	35.14	27.63
				25	4	12	61
	9	10	a	50	4	12	61
1911							
February 7	12	40	p	1/2	6.0		
				25	0	35.25	27.76
	12	30	p	50	0	10	66
February 24	2	25	p	1/2	5.7	35.10	27.70
				25	8	10	68
	2	15	p	50	8	10	68
March 28	1	25	p	1/2	5.8	35.16	27.72
				25	8	17	74
	1	15	p	50	8	17	74
April 20	1	25	p	1/2	6.2	35.08	27 61
				25	1		
	1	15	p	50	1	35.16	27.69
May 3	7	25	a	1/2	6.3	35.14	27 65
				25	3		
	7	15	a	50	3	35.16	27.66
May 20	7	30	a	1/2	7.0	35.17	27.58
				25	0		
	7	20	a	50	0	35.17	27.58

Vestmanhavn.

1912							
June 7	6	00	p	0	7.8	35.16	27.44
				5	8	16	45
				7	8	17	47

Off Slettanæs.

Date	Time hour.	Time min.	Time a. m. or p. m.	Depth m	Temp. °C	Salin. ‰	σ_t
1912							
June 7	5	00	p	0	7.8	35.17	27.46
				10	8	17	47
				20	8	17	47
				30	8	17	47
				40	8	16	45
				50	8	23	51
				60	8	16	45
	4	20	p	66	8	17	47

North of „Sundene".

1912							
June 13	7	30	p	0	8.2	35.21	27.43
				10	1	21	45
				25	1	19	43
				50	1	19	43
				80	1	21	45

Ejde Banken.

1912							
June 13	6	30	p	0	9.2	35.08	27.17
				5	1	08	18
				9	8.9	16	28

Lervigfjord off Andefjord.

1910							
October 27	11	55	a	½	9.0	35.12	27.23
	12	20	p	50	0	14	25
	12	10	p	100	0	14	25
November 11	8	10	a	½	8.0		
				50	0		
	8	30	a	100	1		
November 17	8	50	a	½	7.4	35.14	27.49
				50	4	12	47
	8	30	a	100	4	12	47
December 2	9	50	a	½	7.0	35.14	27.55
				50	6.9	10	53
	9	35	a	100	9	14	56
December 13	2	50	p	½	6.9	35.08	27.51
				50	9	10	53
	2	35	p	100	9	10	53
1911							
January 6	1	25	p	½	6.3	35.10	27.62
				50	3	12	63
	1	10	p	100	3	10	62
January 16	1	25	p	½	5.8	35.03	27.62
				50	8	03	62
	1	15	p	100	8	05	63
January 31	12	40	p	½	5.9	35.01	27.60
				50	9	03	62
	12	25	p	100	9	01	60
February 13	2	10	p	½	6.1	35.07	27.62
				50	1	10	65
	1	50	p	100	0	05	61
February 27	1	40	p	½	5.5	35.08	27.70
				50	6	07	68
	1	30	p	100	6	08	69

(Lervigfjord off Andefjord continued).

Date	Time hour.	Time min.	Time a. m. or p. m.	Depth m	Temp. °C	Salin. ‰	σ_t
1911							
March 28	7	45	a	½	5.7	35.16	27.74
				50	7	12	71
	7	35	a	100	7	12	71
April 4	9	45	a	½	5.8	35.17	27.74
				50	8		
	9	35	a	100	8	17	74
April 22	12	15	p	½	6.1	35.12	27.66
				50	0		
	12	05	p	100	0	08	64
May 4	8	45	a	½	6.3	35.16	27.66
				50	2		
	8	35	a	100	2	16	67
May 18	5	45	p	½	6.8	35.16	27.59
				50	8	16	59
	5	35	p	100	8	16	59

Amount of oxygen.

Vaag Fjord.

Date	Time hour.	Time min.	Time a. m. or p. m.	Depth m	Temp. °C	Salin. ‰	O'_2 ccm of Sat.	O'_2 ccm observ.	$\frac{100\,O_2}{O'_2}$
1910									
June 1				0	8.4	34.72	6.54	8.05	123.0
				12	7.4	35.00	66	7.99	119.9
				23	2	07	70	6.85	102.2

Vaag Fjord, Station 2.

1912									
May 15	6	35	p	19	7.4	35.16	6.65	6.85	103.0
May 24	7	05	p	20	6	16	63	79	102.4
May 25	6	10	a	19	6	17	63	93	104.5

Station 3.

1912									
May 16	5	00	p	20	7.4	35.23	6.65	6.92	104.1
May 24	5	20	p	19	6	17	62	7.11	107.4
May 25	7	35	a	18	7	17	61	45	112.7

Station 4.

1912									
May 16	5	25	p	45	7.4	35.16	6.66	6.68	100.3
May 25	7	10	a	43	6	17	63	92	104.4

Station 5.

Date	Time			Depth m	Temp. °C	Salin. ‰	O'_2 ccm of Sat.	O_2 ccm observ.	$\frac{100\,O_2}{O'_2}$
	hour.	min.	a. m. or p. m.						
1912									
May 16	6	00	p	18	7.4	35.16	6.65	6.88	103.5
May 24	6	20	p	17	7	16	61	7.01	106.1
May 25	6	45	a	19	6	16	63	6.70	101.1

Vaag Fjord, Station 6.

1912									
May 15	4	00	p	63	7.4	35.16	6.65	6.76	101.7
May 24	4	10	p	68	6	16	63	94	104.7
May 25	8	35	a	69	6	17	63	84	103.2

Off Slettanæs.

1912									
June 7	4	20	p	66	7.8	35.17	6.60	7.31	110.8

Vestmanhavn.

1912									
June 7	6	00	p	7	7.8	35.17	6.60	7.43	112.6

Ejde Banken.

Date	Time			Depth m	Temp. °C	Salin. ‰	O'_2 ccm of Sat.	O_2 ccm observ.	$\frac{100\,O_2}{O'_2}$
	hour.	min.	a. m. or p. m.						
1912									
June 13	6	30	p	9	8.9	35.16	6.45	7.66	118.8

North of „Sundene“.

1912									
June 13	7	30	p	80	8.1	35.21	6.56	7.19	109.6

Sands Vaag.

1912									
June 22	7	00	p	0	9.2	34.92	6.43	6.96	108.2
				10	8.6	35.17	49	96	107.2

Nolsø Fjord.

1912									
June 27	6	00	p	0	8.6	35.17	6.49	7.03	108.3
				40	5	17	50	6.96	107.1
				87	5	16	50	7.05	108.5